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Development of action perception:

**Neurocognitive mechanisms underlying
children's processing of others' actions**

Markus Andreas Paulus

The research in this thesis was supported by the Netherlands Organization for Scientific Research (NWO), grant number 453-05-001.

ISBN: 978-94-91027-00-0

Layout by Alter Grafisch Ontwerp (Sandra Geerlings), Nijmegen, The Netherlands

Printed by Ipskamp Drukkers, Nijmegen, The Netherlands

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Development of action perception:
Neurocognitive mechanisms underlying children's
processing of others' actions

Een wetenschappelijke proeve op het
gebied van de Sociale Wetenschappen

Proefschrift

ter verkrijging van de graad van doctor
aan de Radboud Universiteit Nijmegen
op gezag van de rector magnificus prof. mr. S.C.J.J. Kortmann,
volgens besluit van het college van decanen
in het openbaar te verdedigen op dinsdag 28 juni 2011
om 10.30 uur precies

door

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geboren op 12 mei 1980
te Landsberg am Lech (Duitsland)

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Chapter 1

Introduction



“Die Psychologie des Kindes leidet, wie die der Tiere, häufig an dem Fehler, dass die Beobachtungen nicht objektiv interpretiert, sondern durch subjektive Reflexionen ergänzt werden. Infolgedessen werden dann [...] die frühesten, tatsächlich rein assoziativ entstandenen Vorstellungsverbindungen als Akte einer logischen Reflexion gedeutet.” (Wilhelm Wundt, 1913, p. 363).

[“Child-psychology often suffers from the same mistake that is made in animal psychology: namely, that the observations aren’t interpreted objectively, but are filled out with subjective reflections. Thus, the earliest ideational combinations, which are in reality purely associative, are regarded as acts of logical reflection [...].” (Wundt, 1897/1997)]

Development of action perception: Neurocognitive mechanisms underlying children’s processing of others’ actions

The present thesis investigates how young children perceive and process others’ actions. It reports a series of studies employing behavioral observation techniques, eye-tracking and electrophysiological recordings that were designed to examine developmental changes in children’s action perception and the neurocognitive mechanisms that subserve children’s processing of others’ actions. The first chapter of the thesis will introduce the reader to the topic. The first section will provide a general historical background on the topic and will give definitions of the key concepts of this thesis. The second section will familiarize the reader with some main findings of this research area and will introduce the theories that were examined in this thesis. Finally, the third section will give a short overview over the remaining chapters of the thesis.

1. Historical background and Definitions

“Ο ἄνθρωπος φύσει πολιτικὸν ζῶον” [Human is, by his nature, a social being] (Aristotle, Politik 1253 a2). From early on, as exemplified in this quotation from Aristotle’s classical work *Politika*, thinkers have recognized the social nature of human life. Humans live in very different forms of social communities, ranging from small-scale groups to large-scale

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societies with functionally specialized sub-systems (e.g., Luhmann, 1989). Additionally, human social life is very flexible. Humans are able to change the manner of their social behavior and adapt it to new environmental circumstances or novel ideas as evidenced in the many transformations human societies have experienced in the past two thousand years (e.g., Rietbergen, 1998; Weber, 2000). Humans are furthermore unique in their ability to culturally transmit knowledge and skills from one generation to the next (Habermas, 1981; Tomasello, Kruger, & Ratner, 1993). Based on the acknowledgement of these facts, it has been concluded that humans are social beings at core and develop their competencies and characteristics in interaction with other humans (e.g., Brandom, 1994; Buber, 1923; Mead, 1934; Habermas, 1981; Tugendhat, 1979). If other humans and their actions are so vital for human development, then the more concrete questions arises of how human children perceive other people's actions, how they process action-related information and how they are able to learn through the observation of other people's actions.

Even though questions on the nature of intentionality and intentional action control have been a major topic of interest in empirical psychology since its origins (James, 1890; Lotze, 1852), the early psychologists widely neglected questions of how people – and especially children – process the actions of others. In the tradition of British Empiricism and Kantian philosophy, they were mostly interested in questions regarding the nature of sensory-specific stimulus perception, consciousness, and spatial as well as temporal representations. This is exemplified in Wundt's (1913) search for the basic elements of consciousness and the apperceptive integration of these basic elements into higher order mental representations. Following this tradition, research on action mainly concentrated on questions of intentional action control, for example, the relation between consciousness and action control (James, 1890). This changed, however, in the first half of the 20th century.

1.1 Three approaches to action perception in the early 20th century

At least three major psychological movements generated systematic investigations of children's and adults' perception of other people's actions: Behaviorism, Psychoanalysis, and Genetic Epistemology. With the rise of Behaviorism and its critics of a speculative form of psychology that was often based on introspection, psychological research started to concentrate on studying the impact of environmental factors on human behavior. As indicated by its name, behavior became the central category, in contrast to, for example, consciousness or phenomenological reports of subjective experiences. Human behavior was studied as a

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function of learning processes and internal drives (e.g., Hull, 1943). Even though, within developmental psychology, the main focus of behaviorist research was on the application of animal findings to young children (e.g., Bijou, 1955), the impact of other people's actions on the behavior of the individual also became a topic of interest for the behaviorist movement (e.g., Skinner, 1948). Within this approach, other people's actions were mainly conceived of as being conditioned stimuli or rewards that affect an individual's behavior. Children's development was seen as a sequence of learning processes governed by associative and instrumental learning. This approach was further fruitful as it led to a theory of imitation and subsequent experiments that showed how participants could acquire a tendency to imitate by means of reward-learning (Miller & Dollard, 1941)¹. However, neither of these studies controlled for the impact of emulation learning, local enhancement or stimulus enhancement (see Tomasello, 1999). Furthermore, even if it were to be assumed that the participants learned to copy specific actions, by focusing on the behavioral outcomes the cognitive mechanisms that enabled the translation of observed behavior into one's own actions were neglected (cf. Brass & Heyes, 2005).

A wealthier concept of human action perception and processing was pursued within psychoanalytic approaches to the human mind (e.g., Freud, 1917; Fromm, 1932). Freud (1917), for example, suggested that in the course of human development from the oral to the genital phase, children introject or internalize (i.e. build an internal representation of) their primary caregivers' attitude towards certain kinds of behaviors. In other words, he suggested that children become able to anticipate how their caregivers (representing the norms of their society) will react to certain of their behaviors, which the children felt inclined to do, by internally re-enacting or simulating the caregivers' actions. Children are thus able to predict the reactions of others to their actions and this simulation-based prediction allowed them to adapt to the requirements of their society. Though it remained unclear how the proposed mechanism of introjection actually worked, and though these notions were exclusively applied to explain the normalization of behavior in the course of human development, it should be noted that these considerations resembled to some extent the discussions on interpersonal action simulation that take place in contemporary cognitive science (cf. Goldman, 2005). In general, however, psychoanalytic theory formation had no great impact

¹ Interestingly, the seminal studies by Thorndike (1911) indicated that cats and other animals were not able to learn by observation. If a cat was put into a cage, which she could only leave through a door, she was not able to learn how to open this door by observing another cat.

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on contemporary cognitive science as it suffered from mythological impact and highly speculative concepts (e.g., Grossmann, 1989) and has therefore been criticized as being a pseudo-science (Popper, 1994).

The third theoretical approach that contributed to the question of how young children process perceived actions is linked to the name of Jean Piaget. Primarily, Piaget's motivation was the foundation of a Genetic Epistemology with which he wanted to reconstruct the socio- and psychogenesis of an individual's ability for scientific reasoning. In particular, he wanted to historize – by taking recourse to ideas of Hegel (1997) – the by Kant (1787/1998) as apriori assumed categorical structure of human thinking (see for an overview Fetz, 1988). For Piaget, the fundament of all cognitive operations lied in the sensomotoric processes of the first two years of life. In his analysis of early cognitive development, Piaget (1962) developed a theory of action perception and imitation. The basic processes that govern the development of imitation over the six stages of sensorimotor development were assimilation (i.e. the integration of a percept into an existing scheme) and accommodation (i.e. the adaptation of an existing scheme to novel information). In the first stage of sensorimotor development, the newborn is endowed only with inborn reflexes. These reflexes become released by increasingly different stimuli. In other words, infants progressively assimilate different objects into their mental representations (i.e. schemata; cf. Piaget, 1952). Over the next two stages, the reflex schemata become first primary circular reactions through the assimilation of external elements. Insofar as a model's actions resemble infants' own actions, they can be assimilated to a circular reaction and repeated (i.e. imitated). Subsequently, the existence of secondary circular reactions describes the repetition of actions, whose consequences can be visually perceived. Insofar as the visually perceived movements of other people resemble infants' own movements, they can be assimilated and reproduced. In stages 4 and 5, infants become able to assimilate actions of others even though they cannot observe these actions when they perform them themselves. The existence of tertiary circular reactions describes the observation that children systematically try to imitate novel actions, even though they are not yet within their action repertoire. According to Piaget (1962), this ability is not based on a learned association between visual percepts and the kinesthetic perception of one's own body parts as suggested by Guillaume (1925). It is acquired through the coordination and reciprocal assimilation of different schemata, so that the visual percepts serve as indices for the movement. From these stages onwards, imitation is established as an independent function as it differs from a reproductive assimilation. In the sixth stage, infants are able to

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interiorize the accommodative process and to build inner representations of the outer world. This enables them to internally accommodate their schemata before they actually perform them and to defer their imitation of actions. In sum, according to Piaget (1962) the ability to imitate is the result of a developmental process that develops over several stages.

Importantly, one should note that Piaget uses the word “imitation” in a much broader sense than the layperson does. For Piaget, “imitation” refers not only to the copying of another person’s action, but also to the tracing (i.e. reproduction) of objects or physical events by means of body movements and the inner image of an object. Furthermore, he suggests that a “function of imitation ... [is that it makes] new reconstitutions and anticipations possible” (Piaget, 1952, p. 84). In particular, by means of reproductive assimilation of information into an existing scheme, the information is understood (though not on a representational level) and running through this scheme (i.e. “imitation”) enables anticipation of future events. Taken together, according to Piaget domain-general mechanisms such as the accommodative differentiation of schemas and the assimilation of outer events (comprising human actions) into existing schemata subserve infants’ imitation and prediction of other people’s actions.

Although Piaget’s theory stands out in its systematicity (as evidenced in his detailed account on the development of imitation), one has to take into account that his considerations were based on occasional (though systematic) observations of very few subjects. Furthermore, even though his general approach to infant development in terms of sensorimotor processes has inspired many researchers (e.g., Carpendale & Lewis, 2004; Pfeifer & Scheier, 1999; Smith & Sheya, 2010), his entire theoretical framework has been criticized as being on the one hand too speculative and abstract and on the other hand as being descriptive rather than explanatory, i.e. not elucidating the cognitive mechanisms that underlie developmental changes (see for an overview Montada, 2002).

1.2 Definitions

This thesis reports a series of studies that were designed to investigate children’s developing action perception. More precisely, it examines the social-cognitive and neuro-cognitive mechanisms that subserve humans’ developing processing of others’ actions. To this end, this thesis focuses on two interrelated aspects: the first part addresses the mechanisms and developmental changes in children’s action perception as evidenced in their action prediction or their neural responses to perceived actions. For example, how infants anticipate others’

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actions is indicative of infants' representation of this action, and is thus informative with respect to the mechanisms underlying of infants' processing of others' actions. The studies in the second part of this thesis focus on a specific topic of action perception, namely observational or imitative learning. A central question in this research field is, which neuro-cognitive mechanism is used to translate perceived actions into one's own actions (cf. Brass & Heyes, 2005). Furthermore, children's imitation of action also indirectly informs us about how others' actions are processed (cf. Elsner, 2005).

The focus of the first part of this thesis will thus be on children's *action perception*, i.e. the mechanisms involved in children's processing of perceived actions. Although in the literature the concept of *action understanding* is often employed for research on this topic (e.g., Behne, Carpenter, Call, & Tomasello, 2005; Phillips & Wellman, 2005; Woodward & Guajardo, 2002), *action perception* will be used as the central concept of this thesis. This decision is motivated by the following considerations. There is to date no clear definition of (action) *understanding*. In fact, especially in the 20th century, philosophers have continued to argue about the concept of *understanding* and its underlying mechanisms (e.g., Gadamer, 1960; Heidegger, 1927; Tugendhat, 2007; Brandom, 1994; von Wright, 1971; see also Uithol, van Rooij, Bekkering, & Haselager, in press). In its strongest form, understanding an action relies on explicit knowledge about the purpose of and the reason for an action, and thus equals an explanation of an action (cf. von Wright, 1974; see also Bransen, 1999). Even though developmental research has suggested that infants process human actions differently than other events (cf. Spelke et al., 1995; Woodward, 1998), it is questionable whether young children are able to understand actions according to the definition outlined above (e.g., Perner, 2010; Sirois & Jackson, 2006). For that reason, the more parsimonious concept of *action perception* shall be employed in this thesis.

With regard to the translation of observed actions into one's own actions, the concept of imitative learning or *imitation* shall be used to describe children's reproduction (or facilitation of the execution) of an observed behavior. Various definitions have been put forward to differentiate imitation from other concepts such as goal emulation or local enhancement. It has been suggested that imitation should refer only to the acquisition of entirely novel behaviors (Byrne & Russon, 1998). Others have proposed that behaviors should only be called imitative if the reproduction of the observed behavior was based on an understanding of the other's intention (Tomasello, 1999) or if the action was performed with the conscious intention of imitating the other person (Tissaw, 2007). However, all these

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definitions are controversial. With regard to Byrne and Russon's (1998) definition one could object that it is hardly possible to determine if an action is novel (i.e. has never been performed before) for an infant. The other two suggestions connect imitation to a particular mechanism (Tomasello, 1999) or even to a very specific intention (Tissaw, 2007). This is problematic as it is, for example, controversial whether infants possess the necessary cognitive abilities (see Paulus, in press-b). Therefore, in the context of this thesis *imitation* shall be used to describe the relation between a perceived and a performed behavior whereby the performed behavior is sufficiently similar to and also the consequence of (i.e. causally connected to) this similar action (Paulus in press-b).

2. Current approaches

The following section will first briefly present studies on young children's action perception carried out over the past few years. Subsequently, the main theories of this research field, which are of central importance to this thesis, will be introduced.

2.1 Actual findings

In a seminal habituation study, Woodward (1998) presented 5- to 9-month-old infants with an actor grasping one of two toys. After habituation, the position of both toys was switched and the actor grasped either the same toy or took the same movement path and grasped the other toy. Infants showed longer looking times when the actor kept the same movement path and grasped the new toy than when the actor changed the movement path and grasped the old toy. This was not the case when the infants observed a mechanical claw performing the grasping movement (Woodward, 1998) or a hand-dropping instead of a grasping action (Woodward, 1999). These and similar results have been interpreted as evidence for the notion that very young infants are already sensitive to the goal-directed nature of human action (e.g., Woodward, Sommerville, & Guajardo, 2004). Interestingly, when it was clear that the claw was operated by a human agent, 9-month-old infants also dishabituated to a change in the action target (Hofer, Hauf, & Aschersleben, 2005). Reid and colleagues (Reid, Csibra, Belsky, & Johnson, 2007) provided further support for infants' sensitivity to others' action goals. In their study, 8-month-old infants observed complete and incomplete goal-directed actions while their brain responses to these two types of actions were assessed by means of electroencephalography (EEG). The results showed increased gamma-band activity for

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incomplete actions compared to complete actions over the left frontal cortex, indicating a possible neural correlate for infants' processing of goal-directed actions.

However, infants not only perceive the goal-directed nature of others' actions, but are also sensitive towards other components of human action, as evidenced by a study of Behne and colleagues (Behne, Carpenter, Call, & Tomasello, 2005). Infants were handed toys by an experimenter. Occasionally these actions failed because the experimenter was unable or unwilling to finish the handling action. Infants from 9 months onwards discriminated between these two actions, as evidenced by their more impatient reactions in the "unwilling" condition. Furthermore, Daum and colleagues (Daum, Vuori, Prinz, & Aschersleben, 2009) showed that infants are able to use information about another's grasp to infer the size of his target object. In their study they employed a habituation paradigm and showed that 6- and 9-month-old infants looked longer when the initiation of a grasping action (i.e. the aperture size of the grasp) did not fit in with a picture of the actor's grasp of a cup (i.e. full or precision grip at the handle). Even though research has provided evidence that infants and children pay special attention to the goal of an action and prefer to imitate another person's goal over his means (Bekkering, Wohlschläger, & Gattis, 2000; Carpenter, Call, & Tomasello, 2005), these findings indicate that infants also encode the specific way, in which an action was performed.

Children's developing action knowledge is not restricted to simple grasping movements, but also extends to tool-use actions. In two eye-tracking studies, for example, Kochukhova and Gredebäck (2010) and Hunnius and Bekkering (2010) were able to show that infants from 6 months of age onwards are able to anticipate the correct end location of ongoing tool-use actions, which involve tools such as spoons, cups or mobile phones. Further evidence for infants' developing sensitivity to other people's tool use actions comes from studies showing that infants around 1 year of age are able to differentiate between possible and impossible tool-use actions (Schlesinger & Langer, 1999) and that their own tool use benefits from the observation of other's tool-use actions (Elsner & Pauen, 2007).

Whereas the studies mentioned above provide converging evidence for and insight into infants' developing action perception, the social-cognitive and neuro-cognitive mechanisms that underlie children's processing of others' actions have been subject to intense theoretical discussion. Importantly, these theories acted on different anthropological and epistemological assumptions, evolved from various scientific traditions, and thus provided partially contrasting explanations. For the sake of clarity, these theories can be

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differentiated along a number of dimensions. For example, whereas some theories highlight the sensorimotor nature of the processes involved in children's processing of other people's actions (see Daum, Sommerville, & Prinz, 2009), others have argued that action perception is guided by a cognitive architecture that consists of domain-specific core principles that support human infants' reasoning about others' actions (e.g., Carey & Spelke, 1994; Premack, 1990). Another issue concerns whether individual processes as the basic mechanisms of early action perception are stressed (e.g., Gergely & Csibra, 2003) or whether the sociocultural mechanisms that contribute to the developing social understanding are emphasized (e.g., Carpendale & Lewis, 2006). A third question is whether one assumes relative developmental continuity in the mechanisms subserving action perception (e.g., Luo & Baillargeon, in press) or whether one stresses developmental discontinuity in the processing of others' actions (e.g., Barresi & Moore, 1996; Moore, 2006). In the following sections, some of the currently most important theories and mechanisms shall be briefly introduced.

2.2 Motor resonance

The first mechanism, motor resonance, suggests that persons use their own motor system to (i.e. their own action experiences) to process other people's actions. Falck-Ytter, Gredebäck, and von Hofsten (2006) investigated 6- and 12-month-old infants' and adults' proactive eye-movements when they observed goal-directed actions. In particular, participants observed how an adult person moved objects into a bucket. The 12-month-old infants and adults, but not 6-month-old infants showed anticipatory eye-movements to the bucket during the transport action, indicating that they predicted the goal of the ongoing action. Furthermore, the 12-month-old infants did not display anticipatory eye-movements when the balls flew into the bucket in a self-propelled manner. As children's ability to perform grasping and transport actions develops over the second half of the first year of life (cf. Bruner, 1970), the authors interpreted their results as evidence for the claim that 12-month-olds' action experiences underlie their ability to anticipate the target of the ongoing action. To directly investigate the relation between action experiences and action perception, Sommerville, Woodward, and Needham (2005) extended the work of Woodward (1998) with a training study. They provided 3-month-old infants with grasping experience by letting them wear a pair of "sticky mittens" that facilitated infants' picking-up of objects (cf. Needham, Barrett, & Peterman, 2002). Only infants who received this training prior to the test trials showed longer looking

times when the actor grasped the new toy than when the actor grasped the old toy, suggesting that active action experience has an impact on the processing of other people's actions (motor resonance).

These and other studies (e.g., Daum, Aschersleben, & Prinz, 2011; Hauf, Aschersleben, & Prinz, 2007; Kochukhova & Gredebäck, in press; van Elk, van Schie, Hunnius, Vesper, & Bekkering, 2008; Southgate, Johnson, El Karoui, & Csibra, 2010; cf. Hauf, 2007) provide converging evidence for the claim that the processing of one's own and others' actions shares a common representation format (e.g., Longo & Berthenthal, 2006; Meltzoff, 2007; Prinz, 1997). On a neural level, it has been suggested that a human mirror neuron system (MNS) might either underlie (Rizzolatti & Craighero, 2004) or represent (Jacob, 2009) the mapping of perceived actions onto one's own motor repertoire. Functionally, it has been claimed that such a mapping process underlies the human ability to predict the course of others' ongoing actions. In particular, it has been proposed that by means of feeding the perceived action into an internal forward model of the same action, either others' goals or the upcoming course of their action can be recognized and anticipated (Csibra, 2007; Decety & Sommerville, 2003; Kilner et al., 2007; Knoblich, 2008). Furthermore, it has been suggested that motor resonance plays a role in human imitation by activating the same motor program in the observer as in the actor (cf. Heyes & Bird, 2007; see also Meltzoff & Moore, 1997).

2.3 Perceptual learning

Hunnius and Bekkering (2010) showed that 6-month-old infants are able to anticipate the correct goal of an ongoing tool-use action. As infants of this age are not able to perform this action themselves, the authors suggested that infants' anticipations might in this case be subserved by learned visual associations. In other words, through repeated co-occurrence visual inputs become associated with each other and such associations might help infants to predict future events. This interpretation is supported by accumulated evidence of powerful statistical learning abilities even in very young infants (e.g., Altmann, 2002; Kirkham, Slemmer, & Johnson, 2002; Lany & Gomez, 2008; Saffran, Aslin, & Newport, 1996; Smith & Yu, 2008). Further evidence for the impact of visual experience on event prediction is provided by Kochukhova and Gredebäck (2007) who showed that 6-month-old infants use experiences with objects' motion trajectories to predict an their movement paths. As it has been argued that human action forms a special category of physical events (cf. Davidson,

1980), such findings indirectly support the claim that perceptual associations might be an important factor in infants' developing action perception and processing. In line with this, it has been suggested that a number of findings on infants' action perception and prediction can be explained in terms of perceptual learning processes (e.g., Kiraly, Jovanovic, Prinz, Aschersleben, & Gergely, 2003; Moore, 2006; Moore & Povinelli, 2007; Paulus, in press-a; Perner & Ruffman, 2005).

Beyond associations between events, perceptual learning processes are also of relevance when processing information about other's potential actions and their action capabilities. Judging others' action capabilities is especially difficult, when they differ from one's own abilities. Under such circumstances, an action simulation that is based on the observer's own action repertoire would interfere with an adequate evaluation of what others can or cannot do (cf. Ramenzoni, Riley, Shockley, & Davis, 2008). However, humans seem to be surprisingly accurate in adequately judging others' action capabilities. To account for this it has been suggested, with reference to Gibson's (1979) notion of affordances, that the observer is able to use perceptual information in the evaluation of others' actions. More specifically, it has been proposed that observers directly perceive the action-relevant properties of agents in relation to their physical environment (Ramenzoni et al., 2008; Stoffregen et al., 1999). Experiences with the characteristics of the environment and others' actions in the environment allow us therefore to perceive others' action affordances. From a developmental perspective, it has been suggested that this mechanism is involved in children's developing action perception (Rochat, 1995).

2.4 Action-effect binding

Related to ideas about perceptual learning and partially overlapping with the notion of motor resonance is the idea that humans employ learned action-effect associations to process other people's actions. In particular, it has been suggested by proponents of an ideomotor approach to action control that through the repeated co-occurrence of an action and its effects, the cognitive representation of the effect becomes associated with the activated motor code (i.e. bidirectional action-effect associations). When the agent subsequently wants to obtain the same effect, the associated motor program will be activated and the appropriate action will be executed (Elsner & Hommel, 2001; Hommel, Müsseler, Aschersleben, & Prinz, 2001). Developmental research has provided evidence that infants' actions are indeed affected by the salient action outcomes (e.g., Bahrack & Watson, 1985; Gergely, 2002; Mast, Fagen, Rovee-

Collier, & Sullivan, 1980) and it has thus been suggested that infants also employ action-effect associations to control their own actions (Aschersleben, 2006). Extending this approach to action perception, it has been proposed that when infants observe another person performing the same action, they can employ acquired action-effect associations to process this action and predict its outcome (Jovanovic, Kiraly, Elsner, Gergely, Prinz, & Aschersleben, 2007; Jovanovic & Schwarzer, 2007; Kiraly et al., 2003).

In the same vein, it has also been suggested that action effects play an important role in infants' imitation. In line with the ideomotor approach, it has been suggested that infants detect the regularities between observed actions and their effects and use the knowledge about these regularities to activate the correct motor program when they subsequently want to attain this effect themselves (Elsner & Aschersleben, 2003). This hypothesis is supported by findings that showed that infants particularly tend to imitate actions that were followed by a salient action effect (Hauf, Elsner, & Aschersleben, 2004; Hauf & Aschersleben, 2008; for a review see Elsner, 2007).

2.5 Teleological reasoning

The teleological stance theory (Gergely & Csibra, 2003) is rooted in domain-specificity approaches of cognitive development. This family of theories proposes that from early on in development, children differentiate between several domains of knowledge. For example, it has been suggested that young infants already possess a naïve psychology and naïve physics and that they thus reason differently about other humans than about physical objects (cf. Hirschfeld & Gelman, 1994). Furthermore, it has been proposed that their reasoning within each of these domains is governed by a number of (possibly innate) core principles (e.g., Carey & Spelke, 1994; Leslie, 1994). In this tradition, the Teleological stance theory has suggested that infants reason about others' actions by applying a *principle of rational action* (Gergely & Csibra, 2003). This principle holds that already infants assume that others' actions are efficient. It is said to be a core principle that forms “the initial state of infant's naïve psychological theory [...] that is as yet ‘uncontaminated’ by the associations established later in development” (Csibra, Gergely, Bíró, Koós, & Brockbank, 1999, p. 262). Applying this principle infants come to understand and predict others' action goals by observing the actions and taking the situational constraints into account. Additionally, given knowledge about an agent's goal, the principle enables an evaluation of the rationality of the means that were chosen to perform the action (Csibra & Gergely, 2007; Gredebäck &

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Melinder, 2010). Support for this theory has been provided mainly in experiments employing visual habituation paradigms (e.g., Bíró, Csibra, & Gergely, 2007; Csibra, 2008; Csibra et al., 1999; Sodian, Schoeppner, & Metz, 2004). Furthermore, based on a seminal study by Gergely, Bekkering and Kiraly (2002), it has been suggested that infants' imitation is also based on an evaluation of the action's efficiency (e.g., Buttelmann et al., 2007; Schwier, van Maanen, Carpenter, & Tomasello, 2006; Zmyj, Daum, & Aschersleben, 2009).

Taken together, recent theoretical and empirical work has identified several possible mechanisms that might underlie young children's processing of others' actions. The present thesis investigates the impact of these mechanisms on infants' and children's action perception, as evidenced, for example, in their action anticipation and imitation.

3. Outline of the thesis

The next four chapters report investigations of infants' and children's action perception. Chapter 2 confronts a perceptual learning view with the Teleological stance theory. It investigates the relative impact of statistical learning and teleological reasoning on 9-month-old infants' and adults' action prediction by means of an eye-tracking study. Chapter 3 describes an EEG-study on how active experience with an action and its typical sound effect affects 8-month-old infants' subsequent perception of this sound (i.e. acquisition of bidirectional action-effect associations). Chapter 4 describes a study on 14- and 20-month-old children's ability to learn to predict the target of a novel tool-use action on the basis of posture information. Chapter 5 investigates 2.5- to 5-year-old children's ability to evaluate others' action capabilities in a situation, in which an actor needs support from another person.

The next five chapters describe studies on the neuro-cognitive mechanisms subserving imitative learning. Chapter 6 and 7 concern two studies that confront the impact of motor resonance and teleological reasoning on 14-month-old infants' imitation. Chapter 8 puts forward a model of imitation in infancy that integrates the notions of motor resonance and action-effect binding and provides empirical support for it in a study with 14-month-old infants. Chapter 9 extends this idea to a study with human adults. Chapter 10 describes an EEG-study on the neurocognitive basis of imitative learning in infancy. Finally, Chapter 11 – the Epilogue – of this thesis summarizes the most important theoretical insights derived from the experimental investigations and describes possible directions for further research.

Chapter 2

The role of frequency information and teleological reasoning in infants' and adults' action prediction



Based on:

Paulus, M., Hunnius, S., van Wijngaarden, C., Vrans, S., van Rooij, I., & Bekkering, H. (in press). The role of frequency information and teleological reasoning in infants' and adults' action prediction. *Developmental Psychology*.

Abstract

This study investigates the contribution of frequency learning and teleological reasoning to action prediction in nine-month-old infants and adults. Participants observed how an agent repeatedly walked to a goal while taking the longer of two possible paths, as the shorter and more efficient path was impassable. In the subsequent test phase, both paths were passable. In the first test trial, infants and adults anticipated the agent to take the longer path. Unlike adults, infants kept anticipating movements to the longer path even after observing that the agent now took the more efficient path, indicating that the frequency of previous observations dominates action prediction. These results provide evidence, contrary to existing claims in the developmental literature, that frequency learning underlies action prediction in infancy, whereas teleological reasoning might gain importance later on in life.

1. Introduction

The ability to predict others' actions is an important human capacity. It allows for timely planning of one's own reactions to others' actions and is a significant component of proper functioning in a dynamic social environment. Central to the investigation of this ability are the mechanisms humans of different ages rely on to predict others' actions. Moreover, findings about the mechanisms, which subserve action prediction, inform us about how humans perceive others' actions and offer insight into the development of social understanding (cf. Carpendale & Lewis, 2006; Hauf, 2007; Moore, 2006).

One of the prominent cognitive mechanisms of infants' social understanding proposed in the literature is that of teleological reasoning. The teleological stance theory postulates that humans normatively evaluate actions by applying the *principle of rational action* (Gergely & Csibra, 2003). According to this principle, humans tend to expect actions that they infer to be most efficient for achieving one's aims based on the situational constraints (Csibra & Gergely, 1998). It has been suggested that this principle is a core principle that forms "the initial state of infant's naïve psychological theory [...] that is as yet 'uncontaminated' by the associations established later in development" (Csibra, Gergely, Bíró, Koós, & Brockbank, 1999, p. 262). Support for this view comes from experimental studies with both adults (e.g., de Lange, Spronk, Willems, Toni, & Bekkering, 2008; Brass, Schmitt, Spengler, & Gergely, 2007) and infants (e.g., Bíró, Csibra, & Gergely, 2007; Csibra, 2008; Csibra et al., 1999; Csibra, Bíró, Koós, & Gergely, 2003; Gergely, Bekkering, & Király, 2002; Gergely, Nádasdy, Csibra, & Bíró, 1995; Kamewari, Kato, Kanda, Ishiguro, & Hiraki, 2005; Sodian, Schoeppner, & Metz, 2004). Furthermore, computational models of action prediction based on the 'rationality principle' have been shown to fit human predictions for adults in several tasks (e.g., Baker, Tenenbaum, & Saxe, 2006; Baker, Saxe, & Tenenbaum, 2009).

Importantly, most evidence for infants' reliance on the *principle of rational action* to understand and predict others' actions comes from studies, in which infants are habituated to an animated agent (e.g., a ball) or a human, which is passing an obstacle (e.g., jumping over a barrier) to reach its goal (e.g., Bíró et al., 2007; Csibra, 2008; Csibra et al., 1999, 2003; Gergely et al., 1995; Kamewari et al., 2005; Sodian et al., 2004). In a subsequent test phase, two possible test trials without the obstacle are presented to the infants. In the one test trial (the *old event*) the agent continues to perform the jumping movement, although not justified by the situational constraints as the obstacle has been removed. In the other test trial (the *new*

event) the agent takes the direct route to its goal. Infants tended to look longer in the *old event* test trial compared to the *new event* test trial, and it has been suggested that infants show surprise about the agent's inefficient action as it would have been more efficient, and hence by the *principle of rational action* also more likely, to take a direct route (cf. Gergely & Csibra, 2003).

Notwithstanding the appeal of this original explanation, it is important to note that the finding can also be explained differently. More specifically, the finding may be the result of long-term frequency learning by infants based on the actions and events they observe in their social and physical environments. In daily life infants observe that humans and other agents very rarely perform sudden jumps during their movements. Similarly, when infants observe objects that move over surfaces (e.g., a ball), these objects usually move linearly along the surface in a straight path without making sudden jumps or swerves. Importantly, this explanation is in line with findings that statistical learning plays a central role in infants' (e.g., Kirkham, Slemmer, & Johnson, 2002; Lany & Gomez, 2008; Saffran, Aslin, & Newport, 1996; Smith & Yu, 2008) as well as adults' information processing (e.g., Hasher & Zacks, 1984). In particular, it has been suggested that from early on in life humans use frequency information to process perceptual events and actions (e.g., Haith, 1993; Hunnius & Bekkering, 2010; Kochukhova & Gredebäck, 2007; von Hofsten, Feng, & Spelke, 2000). Infants come into an experimental session with some expectations about the movements of agents and objects, which they have acquired through observation in their daily life. It is thus possible that infants might have looked longer at the *old event* trials of the above-cited studies as they infrequently observe agents who perform suddenly jumping movements or moving objects that do not follow linear routes on surfaces (cf. Luo, Kaufman, & Baillargeon, 2009). In other words, the inefficient action (*old event*) happens to be an action which is very infrequent in our world and the infants' reaction to these stimuli might thus be a novelty response to an event they rarely observe. As the inefficient action presented in the *old event* trials is also the more infrequent action, the impact of statistical learning and teleological reasoning on infants' action prediction cannot be disentangled in these studies.

The present study was designed to disentangle the contributions of frequency learning and teleological reasoning to infants' and adults' action anticipation. To this end, we constructed stimulus material in which an animated agent moved from one side of a computer screen to the other to get to another agent. In a learning phase, the agent repeatedly took the longer of two paths, as the shorter (and hence more efficient) path was impassable. In a

subsequent test phase, both paths were open and could be used. If infants and adults rely on frequency information in their action prediction, they should anticipate the agent to continue using the longer path. If they, however, rely on the principle of rational action to predict the agent's actions, they should anticipate that the agent would use the shorter path as soon as it is passable again, as taking this path would be the most efficient way to get to the other side. To examine participants' action anticipations, we measured their overall looking times (Csibra et al., 1999) as well as their proactive eye movements (Eshuis, Coventry, & Vulchanova, 2009; Falck-Ytter, Gredebäck, & von Hofsten, 2006; Hunnius & Bekkering, 2010; cf. Aslin, 2007).

2. Method

2.1 Participants

Participants were 20 9-month-old infants ($M = 9$ months, 25 days; range 9;16 to 10;02) and 14 adults (range 19-32 years). An additional 19 infants did not complete the experiment due to fussiness ($n = 9$), interference of the parent ($n = 1$), procedural or technical errors ($n = 4$), or insufficient data in the test trials or not reaching the habituation criterion ($n = 5$)². The infants were recruited from birth records. Parents gave informed consent for participation and were given a book or monetary compensation for their visit. The adults participated in the experiment in return of 5 Euros or course credit.

2.2 Stimuli

The stimulus materials consisted of introductory movies, learning movies, and test movies. All movies had a size of 1200 by 1024 pixels and were created using Adobe Image Ready 7.0. Three different introductory movies were made and showed a horizontal path on a green background which led from the right side of the computer screen to its middle. In each movie, a cow walked along the path from the right side to the middle, where the path ended, and back. One introductory movie showed how the cow walked along the path, another one showed exactly the same movement of the cow with a transparent oval occluder in the middle of the path, and a third one showed the movement with an opaque occluder (see Figure 1A). The movies were designed for two purposes: First, they enabled the participants to get

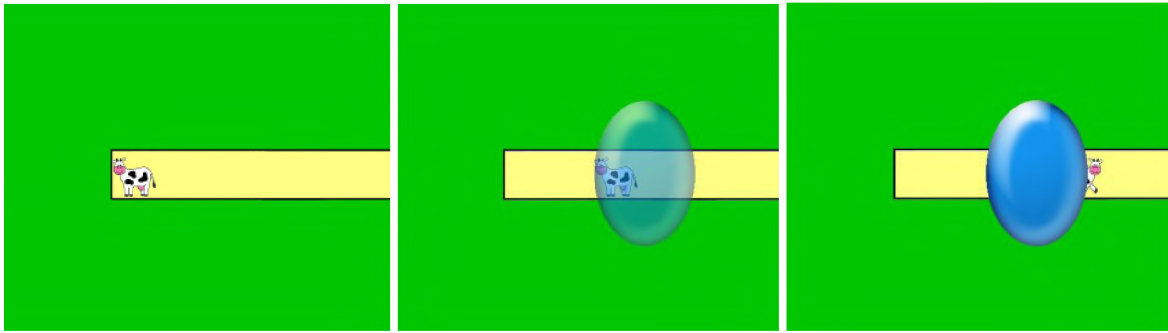
² Although this drop-out rate seems to be high, it is comparable to other habituation-based studies with similar designs (cf. Csibra et al., 1999)

acquainted with the occluder and to learn that the cow continued its path behind the occluder and reappeared from behind it. Second, participants learned that the cow always moved on the yellow paths and not over the green surface, as in every movie she walked until the end of the path and subsequently returned to her initial position.

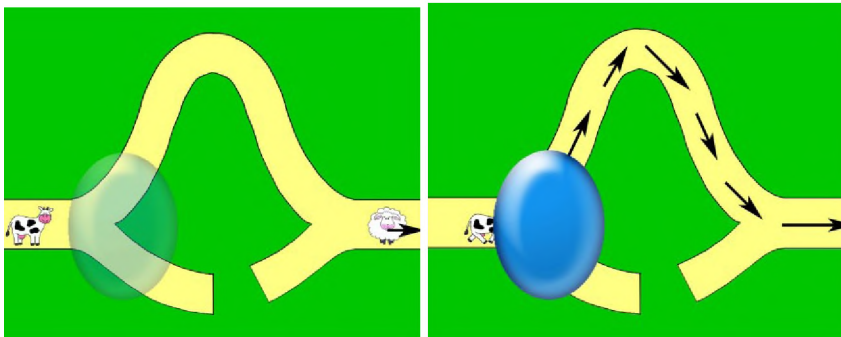
The learning movies showed two paths leading from the left to the right side of the screen. At both ends, the paths converged into a single path (see Figure 1B). One of the paths was obviously longer as it was U-shaped. Importantly, the shorter path did not lead to the other side as it was interrupted by a gap in the middle. The same transparent occluder as in the introductory movies overlaid the crossroad between both pathways on the left side. We introduced an occluder to elicit anticipatory eye-movements (cf. von Hofsten, Kochukhova, & Rosander, 2007) to one of the paths rather than fixations on the moving agent. In other words, as, due to the occluder, participants could not perceive, which path the cow was going to take, their predictive eye-movements to one of the two paths would tell us about their action anticipation. On the left side of the screen a cow was standing on the path, on the right side of the screen there was a sheep. After a short period the sheep wiggled, waited shortly, and moved away to the right until it was off screen. Subsequently, the cow wiggled as a response to the sheep's wiggling. After this interaction between the characters, the transparent occluder gradually turned opaque. The cow started walking along the path and disappeared under the occluder that overlaid the crossroad. After 1.5s the cow appeared again, walked along the long pathway to the other side, and went off the screen after the sheep. The movie ended with a black screen and took altogether 12s. Two versions of this learning movie were made as the path location was counterbalanced, such that the short path appeared on the upper part and the lower part of the screen in an equal number of times.

The test movies differed from the learning movies insofar as there was no gap in the short pathway, so that both pathways were now passable and connected the left and right side. The *old action* movie (see Figure 1C) resembled the learning movie as the cow took the long pathway to get to the sheep. In the *new action* movie, however, the cow took the short pathway. Four *old action* movies were combined to form the *old action test block*, four *new action* movies were combined to form the *new action test block*. Two versions of both test blocks were made to counterbalance path location.

A)



B)



C)

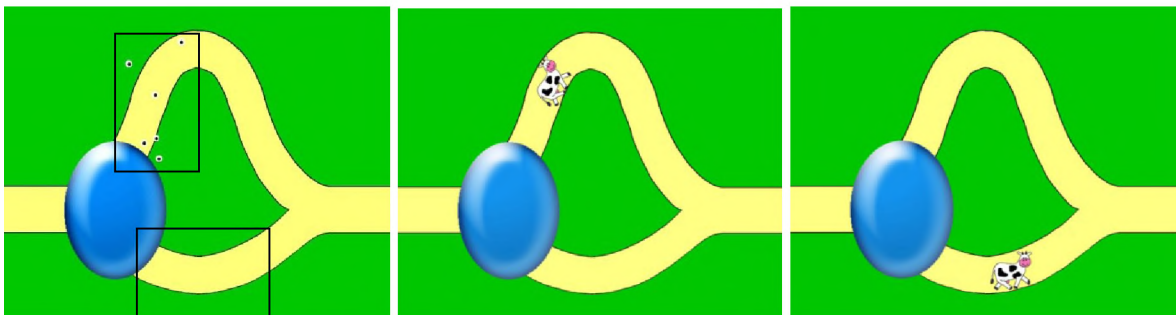


Figure 1. Part A shows examples of the three introductory movies. Part B gives two key frames from the learning movies. The arrows indicate the movement direction. Part C gives in the first picture a projection of infants' first anticipation in the first test trial. The second and third picture show one frame from the old action movie and one frame from the new action movie. The rectangles in the first picture illustrate the approximate position and size of the regions of interest.

2.3 Experimental setup and procedure

The adults were seated on a chair in front of a monitor. The infants were seated in an infant seat on the lap of their parent who was sitting on a chair in front of the monitor. All participants were tested at a viewing distance of approximately 60cm from the monitor. Light conditions were kept low to minimize visual distraction. During the experiment, the gaze of both eyes was recorded using a corneal reflection eye-tracker (Tobii 1750, Tobii Technology, Sweden). The eye-tracking system was integrated in a 17" TFT flat-screen monitor on which the stimuli were shown. The apparatus recorded gaze data at 50Hz with an average accuracy of 0.5° visual angle. The gaze of each participant was calibrated using a 9-point calibration procedure. If seven or less points were calibrated, the calibration was repeated; otherwise the experiment was started.

Infant procedure. Infants participated in a habituation-based experimental procedure which was programmed using Presentation (Neurobehavioral Systems, USA). Once started by the experimenter, the program ran the experiment automatically. It registered the participant's eye movements, calculated looking times, and controlled the stimulus presentation on the basis of the participant's looking behavior.

The experiment started with the presentation of the introductory stimuli. The familiarization stimulus without any occluder was shown once; the stimulus with the transparent occluder and the stimulus with the opaque occluder were both shown twice. Thereupon, an unrelated movie was presented for 10s to attract the infant's attention (attention getter), and the habituation phase was started with the presentation of the first learning movie. The learning movie was presented repeatedly (*learning trial*) and was stopped when the infant looked away for more than two seconds or when the trial reached its maximum duration of 1min. Then, again an attention getter was presented. When the infant looked at the screen, the next trial was started.

The program computed the average looking times of the first three trials and compared this value on-line with the last three looking times. The habituation criterion was reached when the average looking time of the last three trials was less than 50% of the average looking time of the first three trials and this criterion had to be met twice in a row (cf. Csibra et al., 1999). Accordingly, the minimal number of habituation trials was seven. The maximal trial number was set to 15.

When the habituation criterion was reached, a 30s break was introduced during which a short, unrelated movie was presented. Then, the test phase was started which consisted of the presentation of the *new action test block* and the *old action test block*. Both movies had a fixed length of 44s. The order of presentation was balanced between infants. Note that the first 6.5s of both the *old action* block and the *new action* block were identical, as the cow started walking and disappeared under the occluder. To ensure that the looking times towards the test movies reflected infants' response to the nature of the stimulus, we included only participants who watched the stimulus long enough to be able to see which of the two paths the cow actually took. Therefore, all participants were excluded who stopped watching the test trials within the first 6.5s.

Adult procedure. The adults' experiment was run using Clearview (Tobii Technology, Sweden). The familiarization stimulus with the opaque occluder (see Figure 1A) was shown once. Then, the learning movie (see Figure 1B) was presented 8 times in a row as for adults usually no habituation-based procedure is used. Subsequently, the *new action test block* was presented (see Figure 1C).

2.4 Measures

Looking times: To analyze infants' dishabituation responses to both test events, their looking times in the *new action test block* and the *old action test block* were summarized.

Anticipations: Two same-sized regions of interest were defined around the areas where the paths reappeared from behind the occluder (see Figure 1C). A visual anticipation was defined as the first eye movement directed onto one of the two regions of interest during the time the cow was hidden behind the occluder. To analyze anticipations statistically a difference score (DS; for a similar procedure see Corkum & Moore, 1998; Moore & Corkum, 1998) was calculated. To this end, an anticipation to the long pathway was given the value 1, an anticipation to the short pathway was given the value -1, and if no anticipation occurred, the movie was coded with the value 0 (e.g., when participants kept fixating on the occluder or directed their gaze elsewhere on the screen). Data were processed using Matlab and Clearview.

3. RESULTS

Infants: Looking times. Infants completed on average 10.7 habituation trials ($SD = 3.0$). The looking times during the test phase were analyzed by a repeated measures analysis of variance (ANOVA) with the within-subjects factor Test Block (old action, new action) and the between-subjects factor Order of Presentation (i.e., counterbalancing of the *old action* and the *new action* test block). This analysis resulted in no significant effect (all $ps > 0.31$), suggesting that infants did not spend more time looking to the *new action test block* ($M = 23.5$ s, $SD = 7.3$) or the *old action test block* ($M = 24.5$ s, $SD = 9.2$).

Infants: Anticipations. We were interested to which path infants would anticipate in the first movie of the first test trial, as this was the first incidence that both paths could be used. Note that while the cow was under the occluder, there were no perceptual cues about whether the cow actually would take the long path (*old action*) or the short path (*novel action*). Of all infants, 65% showed an anticipatory look in the first test movie, and 92% of them anticipated to the long pathway. A one-sample t -test with DS as dependent variable showed that the average value of 0.55 was significantly different from zero ($t(19) = 4.067$, $p = 0.001$).

For further analyses, the group of infants who first watched the novel action (i.e. the block in which the cow takes the short pathway) was selected, as infants in the other group first watched an action which was incorrect with respect to the predictions of the teleological stance theory. The DS for each of the four movies was separately calculated (see Figure 2A). A repeated-measures ANOVA with DS as the dependent variable and the within-subjects factor Movie (movie 1, movie 2, movie 3, movie 4) revealed no effect of movie ($F < 1$), indicating that infants' anticipation behavior did not change over the four test movies. Accordingly, we averaged the DS over all movies. A one-sample t -test showed that the average DS of 0.25 was significantly different from zero ($t(9) = 3.000$, $p < 0.05$), and infants thus tended to anticipate to the long path over all test trials.

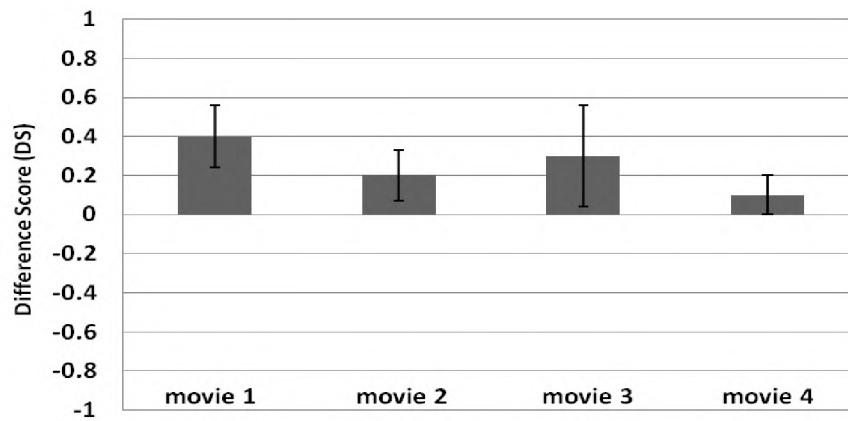
To further examine if infants' tendency to anticipate to the long path could be due to a failure to perceive the gap in the habituation phase or to perceive the lack of the gap during the test phase, the relation between the time infants spent looking to the location of the gap and their test performance was analyzed. To this end a region of interest was defined around the position of the gap and infants' looking times at this region were calculated. On average,

infants spent 12.3 s (SD = 9.7) during the habituation phase looking at the gap. A correlational analysis between the time infants spent looking at the gap and their anticipation behavior in the first test trial ($M = 0.45$, $SD = 0.60$) as well as their performance over all four test trials ($M = 0.25$, $SD = 0.26$) revealed no significant relation, $r = .15$, $p = .54$, and, $r = .18$, $p = .63$, respectively. During the test phase, infants spent on average 436 ms (SD = 589) looking at the location where previously had been the gap (though no fixation was found in the seconds directly prior to the occlusion event of the first test trial). There was no significant correlation between infants' looking to the previous location of the gap and their performances in the first test trial or their performances over all four test trials, $r = .21$, $p = .56$, and, $r = -.12$, $p = .75$, respectively.

Adults. Of all adults, 71% displayed an anticipatory look in the first test movie and 100% of them anticipated to the long pathway. A one-sample t -test showed that the DS of 0.79 was significantly different from zero ($t(13) = 6.904$, $p < 0.001$). We further calculated the DS for each of the four movies (see Figure 2B). A repeated-measures ANOVA with DS as the dependent variable and the within-subjects factor Movie revealed a significant effect of movie ($F(3,10) = 30.028$, $p < 0.001$, $\eta_p^2 = 0.891$). Post-hoc t -tests indicated that the frequency of anticipations differed between the first movie and the following movies (all $ps < 0.001$), which were not significantly different from each other (all $ps > 0.38$). We subsequently averaged the DS over the last three movies. A one-sample t -test showed that the average DS of -0.59 was significantly different from zero ($t(13) = -6.853$, $p < 0.001$), indicating that the adults tended to anticipate to the short path during the last three movies³.

³ To examine whether the effect was mainly driven by trials in which no anticipations occurred, we disregarded all the trials without anticipations and conducted additional analyses. 10 out of 11 infants showed an anticipation to the long path. A binomial test revealed that this pattern was significantly different from chance, $p = .01$. Likewise, 11 out of 11 adult participants displayed an anticipation to the long path, $p < .001$. Next, we analyzed differences between trials. As this data structure does not fulfill the requirements for a Chi-Square analysis (e.g., not every participant contributed data in each trial), we implemented a permutation method to test the significance of differences between groups (cf. Good, 1999). For the infants, the permutation test yielded no significant differences between trials, all $ps > .23$. For the adults, the analysis showed that the first test trial differed from the others (all $ps < .001$), which differed not significantly from each other (all $ps > .21$).

A)



B)

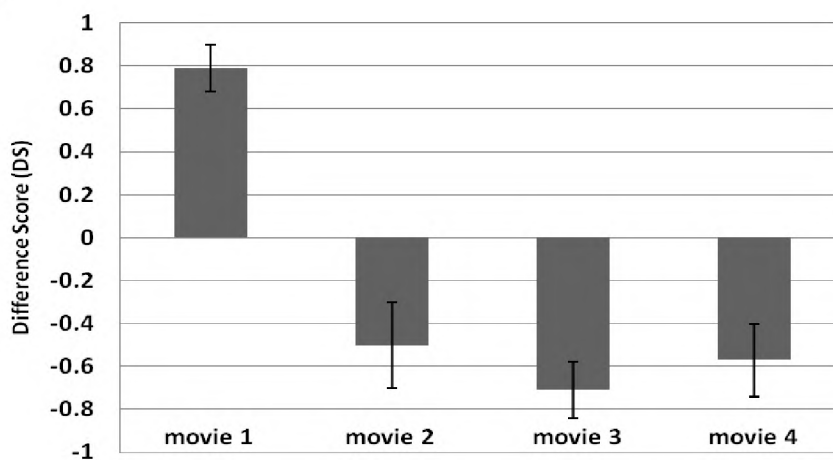


Figure 2. Average difference scores of the anticipations in each movie of the *new action test block*. Positive scores indicate anticipations to the longer path, negative scores to the shorter path, respectively. Error bars indicate standard error. Part A shows the results of the infant participants. Part B shows the results of the adult participants.

4. DISCUSSION

This study examined the mechanisms on which infants and adults tend to base their predictions of others' actions. In particular, the impact of frequency learning and teleological reasoning on action prediction was investigated. To this end, 9-month-old infants and adults observed an agent repeatedly taking the longer of two paths to get to its goal, as the shorter path was impassable. In a subsequent test phase, the shorter path was passable, and a more efficient action was possible. In the first test trial, participants still expected the agent to take the longer path, which shows that infants and adults relied on frequency information (i.e., on

previously observed actions) to predict an upcoming action. After having watched the agent taking the shorter, more efficient path, adults quickly adjusted their expectations. The infants, however, kept anticipating to the long path which suggests that statistical learning is the dominant mechanism of action prediction in infancy rather than the application of the *principle of rational action* (Gergely & Csibra, 2003). Adults, on the other hand, quickly adjusted their predictions when their predictions based on frequency failed.

Interestingly, even adults relied on frequency information in the first test trial. This result is consistent with empirical findings (cf. Hasher & Zacks, 1984) as well as longstanding theoretical approaches (e.g., Hume, 1748) stressing the fact that humans tend to form expectancies on the basis of frequency information and use these expectancies as a default mode of prediction without necessarily reflecting on them. It remains subject to further investigation whether adults relied on the frequency information (i.e., expected the agent to act as before) despite being aware of the changes or because they overlooked (the relevance of) those changes. Importantly, after having observed that the agent changed its behavior when a more efficient action had become possible, adults rapidly considered the novel circumstances and adjusted their expectations. This suggests that adults can overcome this default mode after experiencing a failure to predict actions on the basis of frequency information. Further research is needed to examine whether adults' action anticipations in such novel circumstances are based on their application of the *principle of rational action* (Gergely & Csibra, 2003) or on other mechanisms.

One might argue that infants' repeated anticipations to the long path during the test phase might also be interpreted as resulting from an A-not-B error (cf. Marcovitch & Zelazo, 1999). However, it is very unlikely that our findings can be sufficiently explained by that. First, studies have suggested that the A-not-B error is predominantly found in young children's reaching movements, but not their looking behavior (e.g., Diamond, 1991; Hofstadter & Reznick, 1996). Second, and more important, these kinds of errors have been reported to occur only when A-trials are directly followed by B-trials, which is not the case in our study as we introduced a 30 second break between the learning and the testing phase. Therefore it is unlikely that our task shows the characteristics that are typical for A-not-B errors. The break is furthermore important, as it has been suggested that the "motor memory" of the preceding actions plays a critical role in this task (Diedrich, Thelen, Smith, & Corbetta, 2000). As the infants watched and visually scanned an unrelated, though interesting, movie during the break, we can conclude that the motor memory of the crucial effector (in our case

the eyes) was interrupted in this break by the visual fixations and eye movements on the unrelated display. Thus, it is unlikely that the visual anticipations in the test trials were driven by a simple repetition of a previously executed motor program, but rather they were the result of a learned association between the cow and the path she had been taking.

Importantly, a closer analysis of infants' visual behavior shows that they looked at the location of the gap during the habituation trials and the test trials. This suggests that the infants perceived the presence of the gap during the learning phase as well as its absence during the test phase of the experiment. Furthermore, to exclude the possibility that infants did not look long enough to process the information about the presence the gap in the learning trials or the absence of the gap in the test trials, we performed additional correlational analyses and found no relation between the time infants spent looking at the gap location and their anticipation performance in the test trials. This finding is especially relevant, as one could argue that infants' failure to anticipate to the short path during the test phase could be due to the possibility that they did not see that the short path was initially blocked and therefore assumed that the cow had a preference to take the long path. Additionally, one could argue that infants did not anticipate to the short path because they – even though noticing that there was a gap during the learning trials – did not perceive that the short path was passable in the test trials. However, if these alternative explanations were true, one would expect that the infants who looked longer at the location of the gap (i.e. long enough to process the information) should anticipate to the short path or at least should not show anticipations to the long path anymore. Likewise, the infants who did not look long enough should show continued anticipations to the long path. Therefore, if this interpretation would be true, a correlation between infants' looking times and their test performance should be expected. However, we found no correlation between the time infants spent looking at the location of the gap and their test performance. Yet, most important is the fact that the participants observed from the first test trial on that the cow was now taking the short path. In particular, that the cow was moving on the short path from one side of the screen to the other side provides compelling evidence that the short path was passable. Taken together, the facts that infants looked at the location of the gap during the test trials, that there was no correlation between the time they spent looking at the location of the gap and their test performance, and that they observed during the four test trials how the cow was moving on the short path renders it very unlikely that infants' anticipation behavior could be explained by the assumption that they did not discover that the short path was now available.

Infants' dishabituation responses revealed no significant difference in their looking times between blocks. This finding may at first sight seem to contradict existing findings in habituation experiments which have suggested that infants rely on teleological reasoning in their action prediction. Within the context of our experimental design, the absence of dishabituation effects can be explained by noting that the two measures (i.e., dishabituation times, anticipations) represent two different kinds of underlying processes. Whereas anticipatory eye-movements reveal infants' ability to predict an action, dishabituation times represent infants' "surprise reaction" on basis of a retrospective evaluation of the deviation of the observed behavior from what one would expect (cf. Gredebäck & Melinder, in press). Whereas one can assume that humans quickly acquire an expectation about others' actions, it takes more to be really surprised about an action. For example, knowing that a colleague usually drinks coffee allows one to anticipate what she will drink during her break. Nonetheless one would not be surprised if one day she takes a glass of water, even if not having anticipated that. However, if she would opt for a glass of vinegar, one would be surprised as this action is totally unexpected given one's experiences about what humans normally drink. In the same vein, it has been shown that infants display "surprise reactions" for events that are not only not anticipated, but that violate physical laws (e.g., Baillargeon, 2004; Luo et al., 2009; see also Kuchokhova & Gredebäck, 2007). As our experimental stimuli were specifically designed so as to exclude such non-natural actions, we might thus not find clear "surprise effects" in the infants' dishabituation times. Importantly, though, we do find that infants' predictive looking behavior revealed infants' action anticipations based on statistical regularities that were build up during the course of the experiment.

The essential finding of our study is that the 9-month-old infants kept anticipating to the longer, inefficient path, even though it would have been more efficient for the cow to take the shorter path and negative evidence had been provided on preceding trials. Accordingly, our results provide evidence that infants do not yet predict actions of others based on the *principle of rational action* but rather rely on frequency information in forming action predictions. This finding contradicts the interpretation of previous studies (cf. Bíró et al., 2007; Csibra, 2008; Csibra et al., 1999, 2003; Gergely et al., 1995), but is rather in line with the view that statistical and associative learning forms an important mechanism in infants' early cognitive and social-cognitive development (e.g., Saffran, Pollak, Seibel, & Shkolnik, 2007; see also Barresi & Moore, 1996) and corroborates recent studies on infants' imitation which show limits of infants' ability to rationally assess the actions of others (Paulus,

Hunnius, Vissers, & Bekkering, in press-c). This leaves us with the question of how the ability to evaluate others' actions in terms of efficiency develops. Further research is needed to investigate this in more detail.

Comprehending the mechanisms underlying our ability to predict others' actions is central to explaining the social basis of human cognition and behavior. Key mechanisms are our ability to predict future actions based on past observations, based on our own experiences with these actions, and based on their efficiency (Csibra & Gergely, 2007). Whereas the action prediction and understanding literature has mainly focused on motor and cognitive processes and their relative importance (e.g., Brass et al., 2007; Csibra, 2007; de Lange et al., 2008; Eshuis et al., 2009; Gredebäck & Melinder, in press; Paulus et al., in press-c; Paulus, Hunnius, Vissers, & Bekkering, in press-b; Sommerville & Woodward, 2005), our results make clear that more attention needs to be given to the role of perceptual processes and frequency learning in human action perception and prediction.

Chapter 3

How learning to shake a rattle affects 8-month-old infants' perception of the rattle's sound: Electrophysiological evidence for action-effect binding in infancy



Based on:

Paulus, M., Hunnius, S., van Elk, M., & Bekkering, H. (submitted). *How learning to shake a rattle affects 8-month-old infants' perception of the rattle's sound: Electrophysiological evidence for action-effect binding in infancy*. Manuscript submitted for publication.

Abstract

Bidirectional action-effect associations play a fundamental role in intentional action control and the development of the mirror neuron system. However, it has been questioned if infants are able to acquire bidirectional action-effect associations (i.e. are able to intentionally control their actions). To investigate this, we trained 8-month-old infants for one week to use a novel rattle that produced a specific sound when shaken. Infants were also presented with another sound, which was not related to an action. Thereafter, infants' EEG responses to these two sounds and an additional, unfamiliar sound were recorded. Infants displayed a stronger mu-desynchronization above cortical motor sites (i.e. motor resonance) when listening to the action-related sound than when hearing other sounds. Our results provide therefore electrophysiological evidence that infants as young as 8 months are able to acquire bidirectional action-effect associations and parallel findings of audiovisual mirror neurons in the monkey brain.

1. Introduction

As adults we quickly learn that an action we perform such as, for instance, hitting a drum, produces a specific effect, in our example a characteristic sound pattern. When we encounter the same sound at a later occasion, we can infer that it probably has been the consequence of this specific action. Theories have proposed that such associations between actions and their distal effects (i.e., bidirectional action-effect associations) play an important role in action control (Hommel, Müsseler, Aschersleben, & Prinz, 2001) and the processing of others' actions (Kohler et al., 2002).

In the nineteenth century, Lotze (1852) and James (1890) already suggested that actions are controlled through bidirectional action-effect associations (see also Prinz, 1997). According to this ideomotor theory of action control, action knowledge is acquired through the repeated co-occurrences of actions and their sensory effects and represented in terms of these action effects (Elsner & Hommel, 2001; Hommel et al., 2001; Kunde, Hoffmann, & Zellmann, 2002; Paulus, Hunnius, Vissers, & Bekkering, in press-b; Topolinski, in press; for a recent review see also Nattkemper, Ziessler, & Frensch, 2010). As the intention to elicit a particular sensory effect is assumed to directly activate the motor program that is associated with this effect, acquired action-effect associations underlie the voluntary control of actions (Elsner & Hommel, 2001; Hommel, 2009).

In a similar vein, the discovery of audiovisual mirror neurons in the monkey brain suggests a close link between an action's typical effect and the associated motor program (Kohler et al., 2002). In particular, it was observed that neurons in the monkey's premotor cortex show an increased rate of activation not only when the monkey performs an action himself, but also when he perceives the typical auditory effect of this action. To explain the acquisition and development of mirror neurons, Heyes and colleagues (Catmur Walsh, & Heyes, 2007, 2009; Heyes 2001, 2010; Heyes & Ray, 2000) as well as Keysers and colleagues (Del Giudice, Manera, & Keysers, 2008; Keysers & Perrett, 2004) proposed that mirror neurons might be the product of an acquired association between sensory and motor codes, that is, based on sensorimotor learning.

Even though the acquisition of bidirectional action-effect associations is thought to play an important role in human action control (e.g., Hommel et al., 2001) and the development of mirror neurons (e.g., Del Giudice et al., 2008; Heyes, 2010), little is known

about infants' ability to acquire bidirectional action-effect associations. Research has shown that from early on infants are sensitive to the contingencies between their actions and the effects of these actions in the environment (e.g., Bahrick & Watson, 1985; Mast, Fagen, Rovee-Collier, & Sullivan, 1980; for a review see Moore, 2006). Furthermore, it has been suggested that infants use these contingencies to guide and intentionally control their actions (e.g., Elsner & Aschersleben, 2003; Hauf, Elsner, & Aschersleben, 2004; Hauf & Aschersleben, 2008; Verschoor, Weidema, Biro, & Hommel, 2010). However, it has been argued that some of these results could also be explained by instrumental learning, as infants just repeated the actions that had been rewarded with an interesting effect (instead of having an expectation that the action leads to a particular effect). In other words, it has been suggested that infants' action control is merely based on stimulus-response (S-R) learning and operant conditioning rather than on acquired action-outcome associations (Kenward, Folke, Holmberg, Johansson, & Gredebäck, 2009; Klosssek, Russell, & Dickinson, 2008). Accordingly, more research is needed to investigate if infants can acquire bidirectional action-effect associations that can later be employed to intentionally control actions (e.g., Hommel et al., 2001) or to process other people's actions (e.g., Kohler et al., 2002).

To address the question whether infants are able to acquire bidirectional action-effect associations and whether they indeed "mirror" others' actions (i.e. activate the corresponding motor program when they perceive another person's action) within their own motor repertoire when they perceive the effects of these actions, we examined infants' brain responses to the perception of distal action effects with electroencephalography (EEG). Research with adults has repeatedly shown that spectral power decreases in the mu-frequency band above cortical motor sites provide a direct way of assessing activation in the motor system (e.g., Caetano, Jousmaki, & Hari, 2007). Frequency band analysis has thus become a reliable method to investigate cortical motor activation also in infants (Marshall, Young, & Meltzoff, in press; Nyström, Ljunghammar, Rosander, & von Hofsten, in press; Reid, Striano, & Iacoboni, 2011; Stapel, Hunnius, van Elk, & Bekkering, 2010; van Elk, van Schie, Hunnius, Vesper, & Bekkering, 2008; for a review see Marshall & Meltzoff, 2011). To investigate infants' acquisition of bidirectional action-effect associations, we trained 8-month-old infants for one week with a novel rattle that produced a specific sound effect when shaken. After the training period, infants' electrophysiological responses to the sound were measured. Our main interest was to identify power-changes related to the presentation of the rattle's sound. Typically, power-changes are expressed with respect to a pre-stimulus baseline period or as the

difference between conditions. In the present study we used two other conditions to determine power-changes in the mu-frequency band: Infants' brain responses to a likewise familiar, but non-action related sound (presented through a voice recorder during the training period) and an unfamiliar auditory stimulus were recorded. If infants built bidirectional action-effect associations during their rattle training, perceiving the auditory stimulus that had been the effect of the infants' own actions should activate the associated motor program. This should be reflected in a stronger desynchronization of power in the infants' mu-frequency band above cortical motor areas for the action-related sound compared to the two other sounds that were not action-related.

2. Method

2.1 Participants

The final sample consisted of 15 infants (*range*: 7 months, 8 days to 8 months, 30 days; *average*: 250 days; 6 boys). Four infants were tested but not included in the final sample because of equipment failure ($n=1$) or fussiness ($n=3$). The participants were recruited from public birth records and were healthy, full-term infants without any pre- or perinatal complications. Informed consent for participation was given by the infants' parents. The families received a baby book or monetary compensation for their visit.

2.2 Stimuli

The stimulus material of the training phase consisted of three identical cylindric objects ($d=4.5$ cm; $h=6$ cm; see Figure 1) made out of red plastic, as well as voice recorders (Voicetracer 600, Philips, Germany). When shaken, the objects produced three different sounds (due to their content which could be a bell, a couple of metal disks or screws) and could thus be used as rattles. Additionally, the same three sounds were recorded and put on a voice recorder, so that they could be played to the infants. Importantly, each of the voice recorders contained recordings from only one of the three sounds. Cylindrical plastic boxes, in which the voice recorders could be inserted, served as container so that the voice recorders could be put on the table in a stable position.

The stimulus material of the test phase consisted of recordings of the same three sounds, which lasted for 2000 ms each. Stimuli were recorded digitally using an AKG-3000 condenser microphone and a MOTU 828ml2 audio interface on a MacPro computer in an

acoustically isolated room at 16-bit, 44,100 KHz quality and were controlled for pitch and loudness. Additionally, we used geometric shapes as background pictures on a computer screen while the sounds were presented in the test phase to maintain the child's attention and to avoid head movements.



Figure 1. Figure 1 shows the objects used in the training phase of the experiment. On the left side is the rattle and on the right side the container, in which the voice recorder was inserted.

2.3 Procedure and Design

Training Phase. For the first appointment, infants and parents were visited at home by the experimenter. The experimenter handed over one of the rattles and one voice recorder to the parents. Parents were instructed verbally about the training procedure. They also received a written training schedule, which indicated that they had to train with their infant every day for about one week (the number of training days varied between 6 and 8). Parents were asked to give their infants 5 minutes of training with the rattle and let the infant listen to the voice recorder for 5 minutes each day. In particular, they were asked to offer the rattle to the infant and let him play with the rattle for this time period. Additionally, a Velcro was provided with the rattle. In case infants had difficulties grasping and holding the rattle, parents were asked to attach the rattle to the infants' wrist. For the training period with the voice recorder, the parents were instructed to activate the replay function of the recorder and then insert it into the container and place it in front of the infant approximately 1.5 meters away (i.e. out of reach). During the training with the rattle and the voice recorder, parents were instructed to remove any other toys and to avoid any other sounds in the background (e.g., radio).

It was counterbalanced between days with which object parents were supposed to start the training (i.e. rattle or voice recorder). To ensure compliance with the instructions, parents were asked to write down the exact training times every day on the training schedule and provide information, how their infant reacted to the stimuli. It was balanced between participants which of the three sounds was the action-related sound (AS; caused by shaking the rattle), the non-action related sound (NAS; played automatically from the voice recorder), and control sound (CS; not experienced during the training phase).

Test Phase. The test session was scheduled one day after the last training session in the infant EEG lab of the Donders Institute, Radboud University Nijmegen. During the experiment, the infant was seated in an infant seat in front of a computer monitor. The child's parent was sitting out of view behind the infant. A loudspeaker was located behind the screen. The software Presentation 11.07 (Neurobehavioral Systems, USA) was used to present the three auditory stimuli (i.e., AS, NAS, CS) in a pseudo-randomized order so that the same stimulus was never presented more than two times in a row. At the same time, pictures of geometrical figures were displayed on the screen in a random order that was unrelated to the sound presented. The experiment was conducted until the child lost interest in the sound stimuli, as evidenced by yawning, crying, or falling asleep. The study was set up as a within-subjects design, as the participants were presented with all three auditory stimuli.

2.4 EEG recording and analysis

The EEG data was segmented into 2200 ms time frames per trial, including a 200 ms baseline before stimulus onset and the 2000 ms, during which the stimuli were presented. By means of a filter, frequencies below 0.0159 Hz and above 120 Hz were cut off. A baseline correction was performed employing the 200 ms time frame before stimulus onset. Trials with artifacts were rejected by means of the automatic artifact rejection function of Brain Vision Analyzer, employing the individual channel rejection mode (maximum difference of values in a segment 250 microvolt). On average, 24.8% of all trials were excluded from further analysis, leaving on average 27 trials per infant and per condition. Per infant, on average 27.3 trials for condition AS (range: 10-49), 27.2 trials for condition NAS (range: 9-46), and 26.7 trials for condition CS (range: 9-47) were used the analysis. A two-way repeated measures analysis of variance (ANOVA) with the within-subject factors Hemisphere (C3, C4) and Sound Condition (AS, NAS, CS) and number of included trials as dependent variable revealed no significant differences (all $ps > .44$).

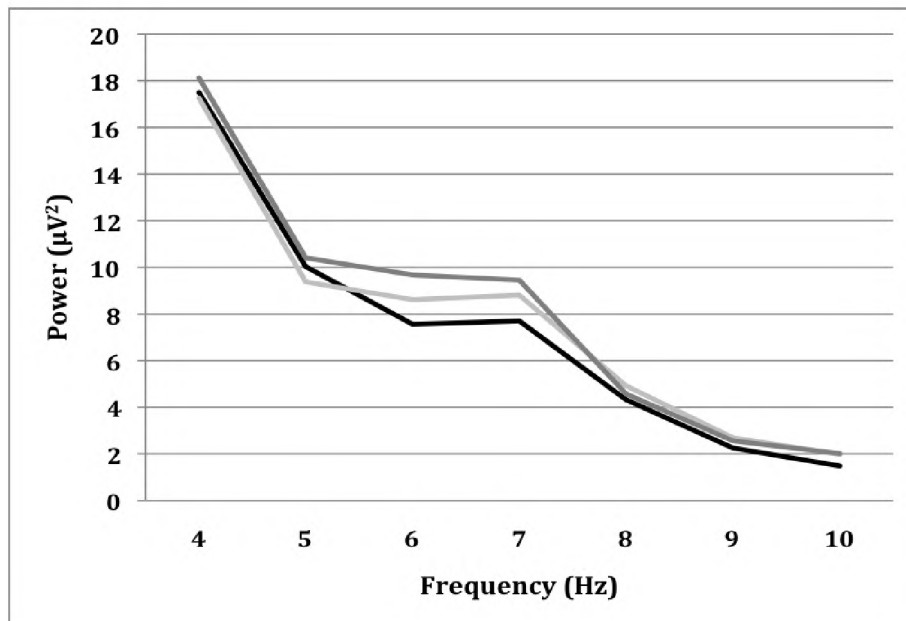
For each trial, fast Fourier transformations (FFTs) were conducted over the 2000 ms time period beginning with stimulus onset and grand averages of the FFTs were calculated for all three conditions. To investigate motor activation during infants' perception of the three different sounds, we focused on the C3 and C4 electrodes, as they are located above the left and right hemispherical cortical motor regions where we expected an effect (cf. Babiloni et al., 2002; Reid et al., 2011). To analyze the average strength of mu-desynchronization for the three sounds, mu-frequency power was averaged over the 6-8 Hz frequency band (cf. Stapel et al., 2010). Data were entered into a two-way repeated measures analysis of variance (ANOVA) with the within-subject factors Hemisphere (C3, C4) and Sound Condition (AS, NAS, CS).

3. Results

It was the aim of the study to investigate whether the power of the EEG signal in the mu-frequency range was more strongly suppressed during the perception of the action-related sound (AS) compared to a similarly familiar, but not action-related sound (NAS) or an unfamiliar sound (CS). An ANOVA revealed a significant main effect of Sound Condition, $F(2,28)=3.719$, $p<0.05$, $\eta_p^2=.21$ (see Figure 2). No significant effect of Hemisphere and no interaction effect were found (all $ps>.11$). So, to further analyze the effect of Sound Condition, we averaged the data across hemispheres. Post-hoc t-tests revealed that the amount of mu-desynchronization in condition AS differed significantly from condition NAS and CS, $t(14)=2.240$, $p<.05$ and $t(14)=2.364$, $p<.05$, respectively, whereas no significant difference was found between the latter two conditions, $t(14)=1.089$, $p=.30$.

To further analyze whether the strength of mu-desynchronization was related to the duration of training, we calculated the correlation between mu-desynchronization and the number of training days. To this end, we computed for each participant a learning score defined as average difference in mu-desynchronization between AS and NAS (AS-NAS-score) as well as AS and CS (AS-CS-score). The analysis revealed a significant correlation between the number of training days ($M = 6.9$ days, $SD = 0.64$) and the AS-CS-score ($r=-.69$, $p<.05$), suggesting that infants showed more motor activation for AS the more they trained with the novel objects. The negative correlation for the AS-NAS-score did not reach significance ($r=-.34$, $p=.21$).

A



B

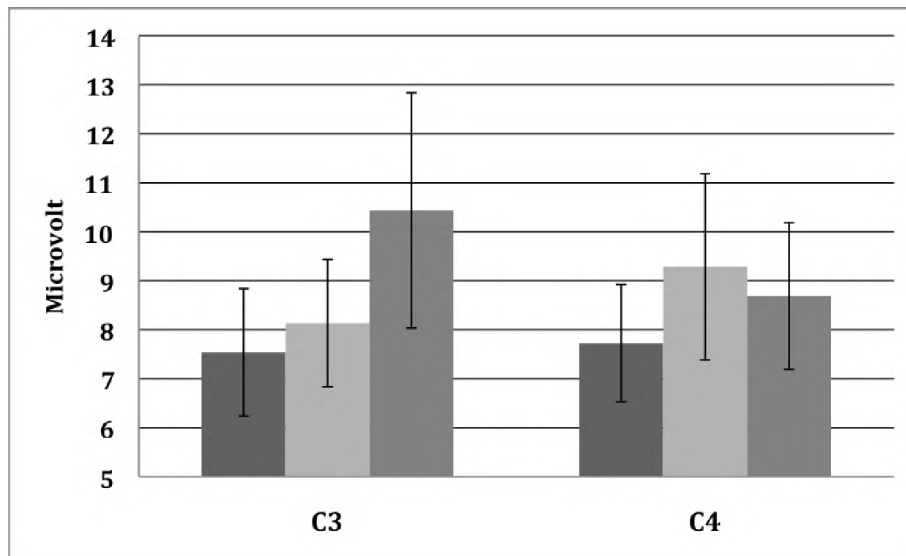


Figure 2. Figure A shows the powerspectra of the three conditions AS (dark line), NAS (light grey line) and CS (intermediate grey line) averaged over infants and over C3 and C4. Figure B displays the grand averaged EEG power for the three auditory stimuli AS (dark bars on the left), NAS (light grey bars in the middle), and CS (intermediate grey bars on the right) at different electrode sites.

Finally, to ensure that the effect of mu desynchronization was restricted to central areas and not widely distributed (i.e. spreading from central over frontal and parietal sites), we performed an additional analysis. To this end, we selected for each hemisphere an additional frontal (Fp1, Fp2) and parietal electrode (P3, P4) and investigated differences between conditions for these electrodes. Data were entered into a three-way repeated measures ANOVA with the within-subject factors Hemisphere (left, right), Side (frontal, parietal) and Sound Condition (AS, NAS, CS). The analysis revealed only a main effect of Side, $F(1,14)=18.501$, $p=.001$, $\eta_p^2=.57$ (all other $ps > .19$), which shows that power was greater over parietal sites ($M=5.94$, $SE=.57$) than over frontal sites ($M=11.62$, $SE=1.69$). Importantly, no effect of Sound Condition, $F<1$, no interaction effect of Sound Condition with Side, $F<1$, or Hemisphere, $F=1$, and no threeway interaction between the factors was found, $F<1$, suggesting that the effect of Sound Condition on the infant mu frequency band was restricted to central sites.

4. Discussion

This study investigates the acquisition of bidirectional action-effect associations in infancy. To this end, infants were trained for one week to use a novel rattle that produced a specific sound when shaken. At the same time, infants were familiarized with another, not action-related sound. After this training phase, infants' EEG responses to these two sounds and an additional, unfamiliar sound were recorded. Our results show that infants displayed stronger mu-desynchronization when listening to the action-related sound than when hearing the other two sounds. Interestingly, the strength of this effect was related to the duration of training. Our results provide therefore electrophysiological evidence that infants as young as 8 months of age can acquire bidirectional action-effect associations.

Following the ideomotor theory, we interpret these findings as evidence that through the repeated co-occurrence of an action and its auditory effect the motor code and the perceptual code (i.e., of the perceived effect) became related to each other, and thus, infants acquired an action-effect association. When infants subsequently perceived the auditory stimulus, the perception of this sound led to an activation of the perceptual code and the associated motor code (cf. Del Giudice et al., 2008; Elsner & Hommel, 2001; Heyes, 2010). Accordingly, the perception of the auditory effect resulted in an activation of cortical motor areas (cf. Elsner et al., 2002) and thus a desynchronization in the mu-frequency band.

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It is important to emphasize that our results cannot be explained by differences between the three auditory stimuli. First, the stimuli were carefully recorded and were controlled for pitch and loudness. Second, the use of the stimuli as action-related sound, non action-related sound and control sound was counterbalanced between participants, rendering it unlikely that our effects were merely due to specific stimulus characteristics. Furthermore, the fact that the desynchronization was significantly stronger for the action-related sound compared to another familiar and an unfamiliar sound, whereas no difference was found between the familiar, but not action-related sound and the unfamiliar sound excludes the possibility that the desynchronization was merely due to a familiarity or a novelty effect.

Interestingly, our analysis did not reveal any difference between the hemispheres, suggesting that the effects were comparably pronounced for both the left and right cortical motor areas. Assuming that the infants did always train with one hand, this finding could suggest that the infants associated a rather abstract motor code (i.e. of hand action in general instead of a, for example, right hand action) with the rattle's sound effect. Therefore motor areas of both hemispheres become activated upon hearing the rattle's typical sound. Alternatively, it might be the case that the infants did not have a strong hand preferences during the training phase, but trained sometimes with their left and sometimes with their right hand. This explanation is supported by research on infants' handedness, which provided evidence for lateral fluctuations in infants' hand preferences (e.g., Corbetta & Thelen, 1999, 2002). As a consequence, infants' might have associated left- and right-hand actions with the sound effect and, when perceiving this sound again, showed an activation in cortical motor areas of both hemispheres. Further research, carefully controlling for infants' left- and right-hand use, is necessary to investigate this issue in more detail.

Previous research has suggested that infants are sensitive to the effects of their own actions from early on and use these effects to guide their actions (e.g., Hauf et al., 2004; Mast et al., 1980; for a review see Elsner, 2007). Hauf and Aschersleben (2008), for example, demonstrated to 7- and 9-month-old infants that pressing one of two buttons led to a salient action effect. Subsequently, infants could play with the buttons. In their experiment, the infants tended to press the button first and longer that led to the salient action effect in the demonstration phase. Although these findings provide evidence for an impact of action effects on infants' subsequent action execution, it was unclear if the effects were due to an acquisition of bidirectional action-effect contingencies. Alternatively, merely reinforcement learning of habitual responses can also explain the results (e.g., Klosssek et al., 2008;

Kenward et al., 2009). Our study, however, provides direct evidence that already 8-month-old infants are able to acquire bidirectional action-effect associations and is in line with other recent findings that employed response latency measures with 9-month-old infants (Verschoor et al., 2010). Following the ideomotor theory (cf. Hommel et al., 2001), these associations might provide the neurocognitive basis of infants' ability to voluntarily control their actions (cf. Gibson & Pick, 2000; von Hofsten, 2007).

Recently, cortical motor activation during action observation (i.e., motor resonance) has been reported in several developmental studies (e.g., Marshall et al., in press; Nyström et al., in press; Reid et al., 2011; Stapel et al., 2010), and it has been suggested that motor resonance is related to infants' own action experience (van Elk et al., 2008). In the study by van Elk and colleagues (2008), however, infants were presented with recordings of human actions and infants' ability to perform these actions was not experimentally manipulated. Our study is the first to systematically manipulate infants' active action experiences and provide electrophysiological evidence that motor resonance is directly modulated by action-experience. Furthermore, supporting the theoretical models proposed by Hommel et al. (2001) and Heyes (2010), our results show that motor resonance can be elicited not only through the observation of an action itself, but also through the perception of the distal effects of this action (cf. James, 1890).

Some studies have shown that the perception of an action leads to activation in the observer's motor cortex (e.g., Marshall & Meltzoff, in press; Nyström et al., in press). Other studies have provided evidence that such motor activation is measurable on a muscular level (e.g., Cattaneo et al., 2007) or in overt behavior (e.g., Kilner, Palignan, & Blakemore, 2003). In the present study, the relation of mu-desynchronization to overt behavior and covert motor activation remains an open question. Further research is thus necessary to investigate whether infants' motor activation upon hearing the auditory effect, which has previously been caused by their own action, is restricted to covert motor activation or can also lead to behaviorally measurable consequences (i.e. the child making sub-threshold or small arm movements during the hearing of the sound).

Our results parallel findings on audiovisual mirror neurons in the monkey brain (e.g., Keysers et al., 2003; Kohler et al., 2002). In particular, it has been found that the perception of an action's specific auditory effect (e.g., cracking a nut) activates the same neurons in the monkey's premotor cortex that are activated when the monkey performs the action himself.

The results of our EEG study show cortical motor activation in response to a specific auditory action effect. It has been suggested that activation in these cortical areas during action perception probably reflects the working of a human mirror neuron system (Kilner & Frith, 2007; see also Caetano et al., 2007). Our findings are thus in line with the suggestion that a mirror neuron system (MNS) might also exist in the human brain (e.g., Rizzolatti & Craighero, 2004). Supporting this notion, we found stronger motor activation for the perception of a sound that was previously the effect of the infants' own actions than of sounds that were either unfamiliar or familiar, but not related to infants' actions. Furthermore, the strength of this effect was partly dependent on the number of training days. In other words, the more active action experience infants had, the more motor activation they showed for the rattle's sound compared to an unfamiliar sound. If we assume that motor activation for the rattle's sound reflect the activation in a human mirror neuron system, then our results provide empirical support for the notion that the development of the MNS is experience-dependent and the consequence of sensorimotor learning experiences (Catmur et al., 2007; Del Giudice et al., 2008; Heyes, 2010) rather than based on an innate matching system (cf. Ferrari et al., 2006). Our results are therefore informative with respect to the question of how the mirror neuron system changes in the course of development (cf. Kilner & Blakemore, 2007).

Our results have implications for current theories on infants' action understanding and imitation, as it has been argued that infants' own action capabilities and experiences are related to these abilities (e.g., Meltzoff, 2007; Paulus et al., in press-b; Paulus, Hunnius, Vissers, & Bekkering, in press-c; Sommerville & Woodward, 2005). For example, it has been argued that the perception of an action or action effect is automatically mapped onto infants' own action system (cf. Heyes, 2010; Ray & Heyes, 2011) and that this mapping process plays an important role in infants' understanding of this action (e.g., Falck-Ytter, Gredebäck, & von Hofsten, 2006). In particular, it has been proposed that such a mapping mechanism enables humans to employ their own motor system to predict the goal of an ongoing action. This suggestion is in line with recent theoretical approaches that stress the embodied nature of infants' action perception and action understanding (e.g., Daum, Sommerville, & Prinz, 2009). Infants' growing experience with different actions and their effects should thus enable them to gradually understand more of other people's intentional action (Barresi & Moore, 2008). Our results provide clear evidence for cortical motor activation during the perception

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of the effects of well-known actions and are thus in line with suggestions that infants map others' actions onto their own motor repertoire.

Chapter 4

Can 14- to 20-month-old infants learn that a tool serves multiple purposes? A developmental study on children's action goal prediction



Based on:

Paulus, M., Hunnius, S., & Bekkering, H. (2011). Can 14- to 20-month-old children learn that a tool serves multiple purposes? A developmental study on children's action goal prediction. *Vision Research*, 51, 955-960.

Abstract

We investigated infants' visual anticipations to the target of an ongoing tool-use action. In particular, we examined if infants can learn that tools serve multiple functions and can thus be used on different targets. Specifically, we addressed the question at what age children are able to predict the goal of an ongoing tool-use action on the basis of how the actor initiates the action. Fourteen- and 20-month-old children watched a model using a tool to execute two different actions. Each way of grasping and holding the tool was predictive for its use on a particular target. Analyses revealed that the 20- but not the 14-month-olds were able to visually anticipate to the correct target during action observation, which suggests that they perceived the initial part of the tool-use action as predictive for its use on an action target.

1. Introduction

Only few non-human species use tools (e.g., de Resende, Ottoni, & Frigaszy, 2008). Yet for humans, their culture and survival appear to be closely linked to their sophisticated use of tools. It has been argued that humans use tools to extend the limits of their own body (Alsberg, 1922). Additionally, researchers have assumed that the ability to develop tools and learn about them by observing other people's tool-use actions is deeply rooted in humans' unique social-cognitive skills, which allow the transmission and accumulation of cultural knowledge (Tomasello, Carpenter, Call, Behne, & Moll, 2005).

While there is disagreement about the evolutionary roots of tool-use (cf. Byrne & Russon, 1998; Csibra & Gergely, 2009; Gehlen, 1940; Tomasello et al., 2005), research has provided substantial evidence that the human ability to use and learn about tools through observation emerges early in development, namely during the first years of life. For example, recent studies on infants' visual expectations show that infants as young as 6 months have acquired rudimentary knowledge about the use of functional objects (Hunnius & Bekkering, 2010; Kochukhova & Gredeback, 2010; Reid, Csibra, Belsky, & Johnson, 2007) and are able to relate the aperture size of an actor's grasping action to the size of the goal object (Daum, Vuori, Prinz, & Aschersleben, 2009). Whereas this knowledge might provide the basis of early means-end behaviors that can already be observed in the second half of the first year of life (Bates, Carlson-Luden, & Bretherton, 1980; Piaget, 1952; Willats, 1999), the ability to use tools unfolds largely during the second year of life (e.g., Barrett, Davis, & Needham, 2007; Berger & Adolph, 2003; Connolly & Dalgleish, 1989; Elsner & Pauen, 2007; McCarty, Clifton, & Collard, 2001; van Leeuwen, Smitsman, & van Leeuwen, 1994) and develops further during early childhood (Smitsman & Cox, 2008).

One important aspect of tool-use is that a tool can be used flexibly in different ways to serve different functions and to act on different targets (e.g., German & Defeyter, 2000; German & Johnson, 2002). A claw hammer, for example, can either be used to hit a nail or to remove it. Based on the different action goals, the hammer needs to be grasped and moved differently. As a consequence, the way of acting on the tool (i.e. grasping and holding it differently) becomes predictive for its subsequent use and enables an observer to predict the goal (i.e. target or end-location) of an ongoing tool-use action (cf. van Rooij, Haselager, & Bekkering, 2008). Given the importance of tools in daily life and for joint activities in

particular, the question arises as to at what age children are able to flexibly predict the goal of an ongoing tool-use action on the basis of how the actor initiates the tool-use action. Interestingly, research on infants' own tool-use abilities has shown that infants' ability to efficiently grasp a tool (i.e., with respect to the goal of the action) improves substantially over the second year of life (e.g., McCarty, Clifton, & Collard, 1999; McCarty et al., 2001). McCarty and colleagues (1999) found that in situations in which participants needed to plan their grasping action in advance, only about 30% of the 14-month-old infants, but 85% of the 19-month-old infants were able to grasp the tool with the appropriate radial grip. This finding provides evidence that infants' ability to efficiently plan their grip with respect to the goal of a tool-use actions develops largely between 14 and 19 months of age. Based on findings that infants' action production influences their action perception (Hauf, Aschersleben, & Prinz, 2007; Paulus, Hunnius, Vissers, & Bekkering, in press-c; Sommerville & Woodward, 2005; Sommerville, Hildebrand, & Crane, 2008; van Elk, van Schie, Hunnius, Vesper, & Bekkering, 2008), we hypothesized that infants' ability to predict the target of an ongoing action by taking into consideration the way a tool is initially being grasped and acted upon should develop between 14- and 20-months of age.

To investigate this hypothesis we employed a predictive looking paradigm. This paradigm is based on findings that infants visually anticipate the target of object-directed actions they observe (Falck-Ytter, Gredebäck, & von Hofsten, 2006; Hunnius & Bekkering, 2010; see also Gredebäck, Johnson, & von Hofsten, 2010). In our study, infants watched a series of short action sequences in which an actor performed two different tool-use actions with the same tool, either using it to insert it into a box or to hit on a bell. The way the model grasped and subsequently held the tool (i.e. which part of the tool was visible) was predictive of its use on one of the two targets. If infants are able to learn to predict the target of the ongoing tool-use action, we expected them to visually anticipate to the correct object on the basis of the model's way of holding the tool.

2. Method

2.1 Participants

The final sample of the study consisted of 32 infants, including sixteen 14-month-old infants (*range*: 13 months, 15 days to 14 months, 30 days; mean age 423 days; 11 boys) and sixteen 20-month-old infants (*range*: 20 months, 1 day to 21 months, 10 days; mean age 624 days; 7

boys). Five additional 14-month-olds and four additional 20-month-olds were tested but not included in the final sample because of general inactivity, refusal to remain seated, or inattentiveness during the experiment. The participants were recruited from public birth records and were healthy, full-term infants without any pre- or perinatal complications. Informed consent for participation was given by the infants' parents. The families received a baby book or monetary compensation for their visit.

2.2 Stimuli

The stimulus material consisted of movies which displayed short action sequences depicting the use of a tool. They showed a frontal view of a male model sitting at a table (see Figure 1B, 1C). The face of the actor was not shown to prevent infants from focusing attention on his face rather than on the ongoing action (cf. Falck-Ytter et al., 2006). Before the actions started, the tool was lying in front of the actor on the table. The tool (see Figure 1A) was a gray object. It had a long shape (about 18 cm) and consisted of two parts which were of distinct color (light grey and dark grey). The tool was placed in a vertical position to the body of the actor so that one end of the tool was always directed towards him. On the left and right side of the table, there were two target objects on yellow cloths, a bell and a box with a small opening on top.

During the tool-use action sequence, the actor grasped the tool with his right hand at one of its ends and moved his hand with the tool straight away from his body. If the tool was grasped with a full grip at the dark grey end, then the actor always inserted the light grey part into the box and turned it as he would do with a key. If the tool was grasped with a precision grip at the light grey end, the actor brought it to the bell and hit the bell with the dark grey part. No other action combinations of type of grasp, tool-use action, and target object were performed. To draw infants' attention to the action target and not to any acoustical effects of the actions, the stimulus movies were presented without sound. Both action movies had a duration of approximately seven seconds (see Figures 1 B and 1 C for key frames). The movement path which the actor performed with the object consisted of two phases: an ambiguous phase (starting when the model grasped the tool, approximately 3-4 seconds after stimulus onset) in which the actor's movement was ambiguous with respect to the two possible target objects, as the actor moved his hand along the middle line between both target objects; and the subsequent phase (starting approximately 5-6 seconds after stimulus onset), during which the actor deviated from the midline and the tool was brought to one of the two

target objects. Note that during the ambiguous phase only the way of grasping the tool and the orientation of the tool were predictive of the action's target.

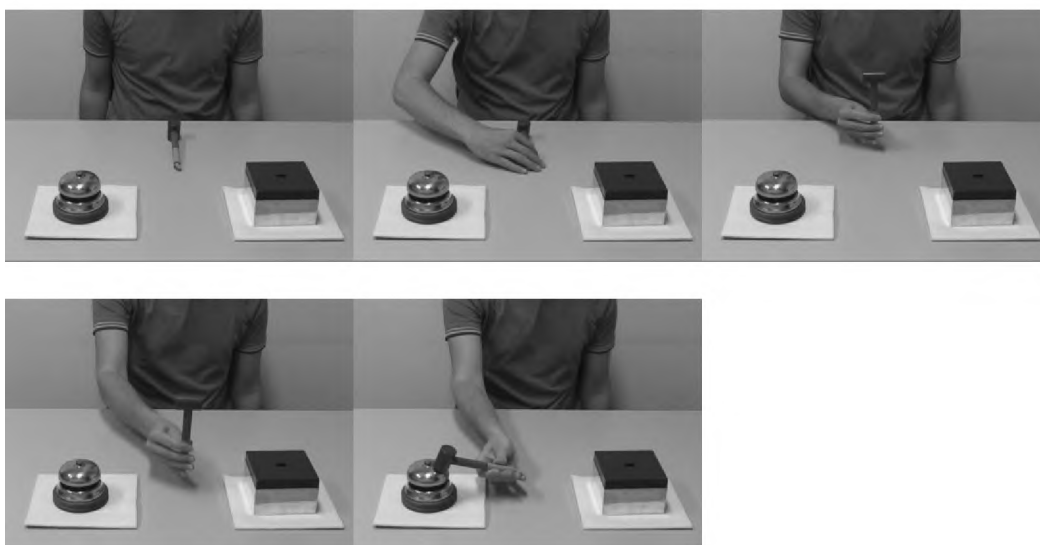
For the action sequences, the part of the tool which was grasped by the actor, the position of the target objects (left or right on the table), and the initial orientation of the tool on the table (which end was pointing to the actor) was counterbalanced. From each of the eight ($2 \times 2 \times 2$) possible combinations two movie versions were made, and thus the stimulus material consisted of 16 action movies.

Piloting with similar stimulus material showed that infants would attend to the tool-use actions for approximately twelve action sequences. Therefore, twelve of the 16 action sequences were composed pseudo-randomly to create movies, which served as stimuli in the experiment. The action sequences were always presented in an ABBABAABABAB order. Note that all trials, in which the target were presented on the same side of the table, were blocked within a movie. Before each block, a still frame (duration 3 seconds) was presented to allow infants to become familiar with the scene. Eight different versions of these movies were composed out of the action sequences in a way that all conditions (i.e. action sequences) were balanced over all movies. Furthermore, the first two action sequences in every movie showed each of the two actions that could be performed with the tool (see Data analysis section).

A



B



C

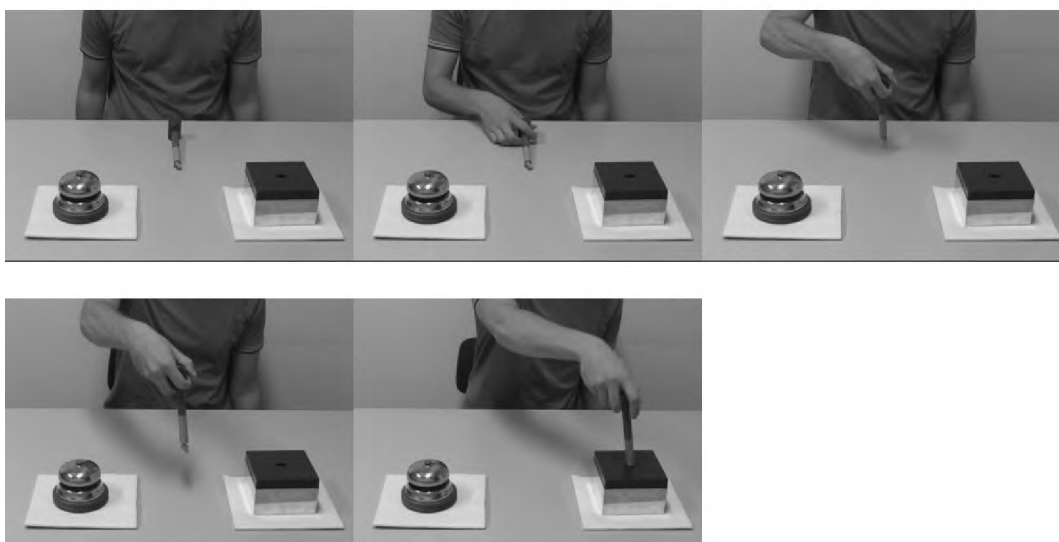


Figure 1. Figure A shows the tool used in the experiment. Figures B and C give each five key frames from two different stimulus movies.

2.3 Experimental setup and procedure

The infants were seated in an infant seat on the lap of their caregiver. The caregiver sat on a chair that was approximately 60 cm away from the computer monitor. The gaze of both eyes was recorded using a corneal reflection eye-tracker at 50 Hz with an average accuracy of 0.5° visual angle (Tobii 1750, Tobii Technology, Stockholm, Sweden). The stimuli were shown on a 17" TFT flat-screen monitor. A 9-point calibration procedure with a 3 x 3 grid of calibration points was used to calibrate the gaze of each participant before testing. If only seven or less points were calibrated successfully, the calibration of the missing points was repeated; otherwise the experiment was started. First, an attention getter was presented to attract infants' attention to the screen. Then, the experimenter started the experiment with a button press.

2.4 Data analysis

We analyzed infants' visual anticipations, i.e. their first eye movement to one of the two target objects during the ambiguous phase of the tool-use action (cf. Falck-Ytter et al., 2006), using a custom-made eye-tracking data analysis software (GSA, Donders Institute for Brain, Cognition and Behaviour, The Netherlands). To this end, two same-sized areas of interest were defined around both targets. Only the last ten of the twelve action sequences within a movie were analyzed because infants saw both actions in the first two action sequences for the first time (see Stimuli section). Measures were taken separately for each trial and then averaged over the ten trials for every participant.

3. Results

Infants showed anticipatory looks to one of the two targets during the ambiguous movement phase of the tool-use action on average in 53% (14-month-olds: 57%; 20-month-olds: 49%) of the action sequences. For further analysis we dismissed the trials in which infants did not anticipate to either of the two target objects, but showed in their looking pattern that they only followed the action or did not pay attention. An analysis of infants' first anticipatory looks to one of the two target objects revealed that 69% (SE = 6.9) of the 20-month-olds' first look were directed to the correct target of the ongoing action, whereas the 14-month-old infants directed their gaze in 49% (SE = 5.1) of the trials to the correct target object. One-sided t-tests revealed that the 20-month-old infants directed their first look significantly more

often to the correct target object, $t(15)=2.693$, $p<0.01$, whereas the 14-month-olds showed no systematic effect in their anticipation behavior, $t(15)=-0.251$, $p=0.40$.

For further analyses of infants' anticipations and changes in anticipation frequency throughout the task, we divided the ten test trials into three blocks (see Figure 2). The first block included the first four trials and the second and third block included three trials each. Note that not every participant contributed data to each block as infants anticipated on average only in 50% of the trials. As a result, data points could be dependent (e.g., when participants contributed data for block 1 and block 2), but also independent (e.g., when the participants did not contribute data for block 3). As this data structure does not fulfill the requirements for conducting an analysis of variance (ANOVA), we implemented a permutation method to test the significance of differences between the groups. Permutation methods allow to calculate the probability that an observed data set can be explained by the null hypothesis without relying on further assumptions (see for a review Good, 1999). The analyses revealed that there was no significant difference between the blocks, neither for the 14-month-olds (all $ps>0.32$) nor for the 20-month-olds (all $ps>0.16$), suggesting that there was no improvement of performance over time.

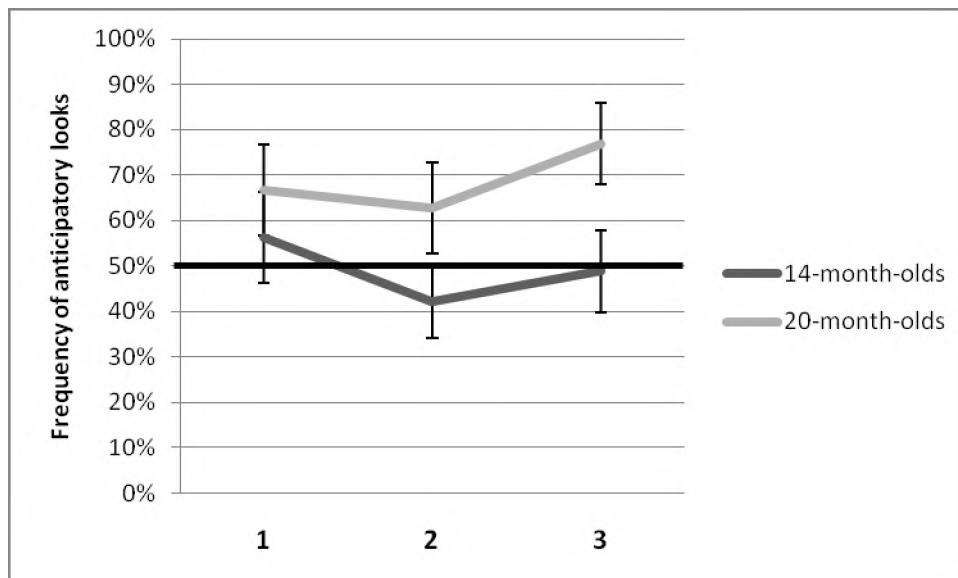


Figure 2. The figure shows infants' performances split up into three blocks (1-3). The first block comprises the first four test trials and the second and third block three test trials each. Error bars indicate standard error of the means. The bold horizontal line emphasizes the 50%-value.

To examine whether infants' anticipation performances were different with respect to the two ways in which the tool could be used, we compared infants' performances in both conditions. The analysis (based on a permutation method) shows that the number of 14-month-old infants' correct anticipations was not different between the conditions in which the dark (43%) or the light grey end (57%) was grasped, $p=.25$. The same pattern of results was obtained for the 20-month-old infants whose performance did not significantly differ between the conditions in which either the dark grey (60%) or the light grey end (73%) was grasped, $p=.29$. This suggests that there were no significant differences in visual saliency or complexity between conditions for the infants.

4. Discussion

The aim of this study was to examine whether 14- and 20-month-old infants and toddlers can learn to predict the target of object-directed tool-use during an ongoing action by taking into consideration the way a tool is initially being grasped and acted upon. Infants' anticipatory eye movements and their looking times revealed that the 20-month-old toddlers, but not the 14-month-old infants anticipated the actor to move towards the target object of the ongoing tool-use actions. This suggests that the 20-, but not the 14-month-old children recognized the initial part of the tool-use action as predictive for the target on which the actor was going to act upon.

Our findings add to recent studies on infants' developing knowledge about functional object use. Infants from 6 months acquire knowledge about objects' usual end locations (Hunnus & Bekkering, 2010; Kochukhova & Gredeback, 2010; Reid et al., 2007). Additionally, they are able to use grip apertures to predict the object that an actor is going to grasp (Daum et al., 2009). McCarty and colleagues (1999) showed that infants' own tool-use abilities, in particular their ability to grasp a tool efficiently with respect to its final use, improve largely over the second year of life. However, an important task in cultural learning is to realize that tools can be flexibly used in different ways and on different targets. Our study thus extends the previous findings by showing that around 20 months of age infants can learn to predict that a certain tool can be used in a functionally flexible way on different targets.

What are the cognitive mechanisms that allow 20-month-old, but not 14-month-old infants to predict the target of an ongoing tool-use action? Three possible mechanisms might

underlie this ability and will be discussed in the following paragraphs: statistical learning, affordance perception, and motor resonance.

The first notion, associative or statistical learning, suggests that infants acquire associations between perceptual events when these events occur frequently in close succession to each other (e.g., Kirkham, Slemmer, & Johnson, 2002). In the present study, infants might have associated the appearance of the hand or of the visible end of the tool with the target and used this information to predict the goal of the ongoing action. This explanation is partially supported by studies that show that perceptual aspects play a major role in infants' learning about tools (e.g., Bates et al., 1980). Moreover, recent findings that have provided direct evidence for the importance of statistical learning in infants' action prediction (Paulus et al., in press-a).

A second mechanism, affordance perception, is based on the idea that action possibilities are directly perceivable (Gibson, 1979). Research with infants has provided evidence that object affordances can already be perceived in the first year of life (e.g., Paulus & Hauf, in press; see also Gibson & Pick, 2000), and it has been suggested that infants' learning about the use of tools might be based on the detection of affordances (Lockman, 2000). In our study, grasping the dark grey end of the tool might have directed the observer's attention at the tool's thin end that fitted into the hole of the box-like target. Thus, the perception of the thin end afforded the inserting action into the opening. Likewise, one can assume that the hammer-like ending afforded the hitting action on the bell.

The third mechanism that might provide an explanation for our results is motor resonance. It has been suggested that motor resonance, a process of direct perception-action matching, might support our capacity to predict the goals of other people's actions (Knoblich, 2008; Wilson & Knoblich, 2005). Previous research has indeed demonstrated that an infant's own action capabilities and experiences are related to how they perceive the actions of others (e.g., Paulus, Hunnius, Vissers, & Bekkering, in press-c; Sommerville et al., 2008; van Elk et al., 20087; cf. Hauf, 2007). As infants' own tool-use and action planning abilities improve over the second year of life (e.g., Cox & Smitsman, 2006; McCarty et al., 1999), they might have matched the observed action onto their own motor repertoire and might thus have used their own experiences with complex tool-use actions to predict the goal of the observed tool-use action.

All three mechanisms provide thus explanations for the 20-month-old children's performance. However, a more thorough consideration of our findings suggests that some explanations are more likely with respect to our findings than others. Concerning associative and statistical learning it has frequently been suggested that such learning should occur gradually, based on the repeated experience of successive events (e.g., Hihara, Obayashi, Tanaka, & Iriki, 2003; Visalberghi & Tomasello, 1998). A closer inspection of the data, however, showed that there was no gradual improvement of performance over time, neither for the 14-month-old nor the 20-month-old infants. In particular, infants did not perform better in the third block than in the first or second block of trials. Additionally, infants show sophisticated statistical learning capabilities with far more complex stimuli already during their first year of life (e.g., Fiser & Aslin, 2002; Kirkham et al., 2002; Saffran, Pollak, Seibel, & Shkolnik, 2007), whereas in our study even 14-month-old infants showed no improvement over the 12 trials. Nevertheless, one cannot fully exclude the possibility that the 14-month-old infants might have needed more learning trials to learn the relation between the initial tool grasping action and the action's goal object. For example, in a study by Woodward and Guajardo (2002), 12-month-old infants needed 9 habituation trials to acquire knowledge about an actor's target. However, it should also be noted that the 20-month-old children showed good performances from the first test trials onwards. Such a rapid acquisition of knowledge that does not rely on many repetitions of the same events is usually interpreted as a sign for a cognitive insight into the relation between the events rather than for associative learning between meaningless stimuli (Kummer, 1995; Visalberghi & Tomasello, 1998). This pattern of results renders it unlikely that statistical learning is the most important mechanism subserving participants' performances in our task.

Concerning the impact of affordance perception, one might object in a similar manner that already 6- to 12-month-old infants are able to perceive the affordances of objects (e.g., Adolph, Eppler, & Gibson, 1993; Paulus & Hauf, in press). However, in tool-use not only affordances between a person's effectors and objects but also between different objects (i.e. the tool and its target) have to be detected (Lockman, 2000). We can assume that the perception of these kinds of affordances is more difficult and might thus develop later, maybe between 14 and 20 months of age as indicated by our results. However, it remains unclear why children's ability to detect these affordances develops over the second year of life.

The last theoretical notion, motor resonance, might offer the most plausible explanation for the age differences that we found in our study. As mentioned before, it has

been suggested that in an effort to predict others' actions people employ their own motor system (Knoblich, 2008; Wilson & Knoblich, 2005), thus infants' own tool-using skills should also affect their performance in this task (cf. Daum, Prinz, & Aschersleben, in press). The fact that infants' own tool-use and action plan abilities improve largely over the second year of life (e.g., McCarty et al., 1999), might underlie the fact that 20-month-old infants picked up the relevant information immediately and not the 14-month-old infants. However, to further validate this claim infants' own tool-use abilities should be more directly assessed in future studies.

Further research is thus necessary to investigate the impact of each of these mechanisms on infants' beginning understanding of other people's tool-use actions in more detail. For example, directly assessing infants' tool-use abilities, manipulating the number of learning trials, and changing the affordances between tool and target would provide more insight into the developmental trajectory of this ability. However, whatever the precise psychological mechanism might be, our results provide evidence that 20-, but not 14-month-old infants are able to flexibly predict the target object of an ongoing tool-use action.

Chapter 5

Whom to ask for help? Children's developing understanding of other people's action capabilities



Based on:

Paulus, M., & Moore, C. (in press). Whom to ask for help? Children's developing understanding of others' action capabilities. *Experimental Brain Research*.

Abstract

We often rely on other people's help to accomplish tasks and to attain goals. People, however, differ in their physical action capabilities. Some persons are therefore better able to provide help than others. We investigated 2.5-, 3.5-, and 5-year-old children's ability to take other person's action capabilities in a helping situation into account. To this end, they observed a protagonist who needed the help of friends to accomplish several tasks. For each task, two friends were available but only one was physically able to provide the help. Our results showed a developmental effect with children in the older two groups performing significantly better than those in the youngest group. Additionally, we found evidence that the 5-year-olds outperformed the younger age groups in their ability to justify their choice. Our findings thus suggest that children's ability to consider others' physical action capabilities in helping situations develops around 3 years of age. The results are interpreted in terms of children's ability to perceive others' affordances. The implication of these findings for theories on the development of action understanding and joint action are discussed.

1. Introduction

Imagine searching around for a lost object. Eventually you see it on the top of a high cupboard, but it is too high for you to reach. Luckily, there are some people around you whom you could ask for help. Clearly, as you want to retrieve an object from a high cupboard, you would ask the taller person to help you, but not the smaller person. As this example nicely illustrates, the ability to correctly judge other people's action capabilities plays an important role in our social life, not only in collaborative, but also in competitive situations. Whereas adults indubitably possess a certain proficiency in taking others' action capabilities into account when looking for help, almost nothing is known about the development of this ability in childhood.

Generally, young children rely on other persons' help to a great extent. It is well established that young children show social referencing behavior when they are uncertain about situations (e.g., Moore, 2006; Walden & Ogan, 1988) and they seek information (e.g., Baldwin & Moses, 1996) and help from others to accomplish tasks and attain goals (e.g., Newman, 2000; Puustinen, 1998). However, as illustrated by the presented example, proper functioning in a dynamic social environment requires sophisticated knowledge about with whom to interact to attain a goal and whom to ask for help or for information in certain situations.

Interestingly, recent research on children's selective social learning has indicated that preschoolers use information about the success of a person's past actions (Birch et al. 2008), or the past accuracy of information provided by a person (Corriveau & Harris, 2009; Pasquini, Corriveau, Koenig, & Harris, 2007), to decide on whom to rely when different persons offer conflicting information. For example, it has been shown that 4- but not 3-year-old children selectively trusted a previously correct person in a word learning situation, when he gave different information than a previously incorrect or ignorant speakers (Koenig & Harris, 2005). Interestingly, a person's past accuracy seems to be more important than an actor's age as preschoolers rely more on a previously accurate person than on an older person (Jaswal & Neely, 2006). Furthermore, selective learning is not restricted to the acquisition of novel words. Rakoczy and colleagues (Rakoczy, Warneken, & Tomasello, 2009) showed that 4-year-old children also preferred to learn novel rules (i.e. normative appropriate actions) from a previously reliable compared to an unreliable model.

The reviewed literature provides evidence for preschool children's selective reliance on persons when acquiring novel knowledge. Whereas these studies have provided important insights, research has neglected the domain of others' physical action capabilities. Research with adults has shown that humans are quite proficient in estimating other people's action capabilities (e.g., Stoffregen, Gorday, Sheng, & Flynn, 1999) and subsequent research, informed by Ecological Psychology (see Marsh, Johnston, Richardson, & Schmidt, 2009, for a current overview), has suggested that such an estimation is based on the detection of action-relevant properties of other agents in relation to their environment (i.e. action affordances; Ramenzoni, Shockley, Fajen, Riley, & Turvey, 2008). Knowledge about the development of this ability is of relevance for developmental psychologists as it provides insight into children's ability to select appropriate persons when seeking help (e.g., when we need to retrieve something from a high cupboard). Furthermore, this domain is of relevance for researchers interested in the development of the ability to engage successfully in joint action because efficient interaction with others relies on an appropriate evaluation of their action capabilities (Sebanz, Bekkering, & Knoblich, 2006).

The present study investigated the development of children's understanding of others' action capabilities. To be able to examine systematically children's evaluations of other's action capabilities across a number of different person characteristics (e.g., such as strength or height) we decided to employ a third-person helping task in which dolls represented the actor as well as possible helpers in a number of different situations (for comparable third-person approaches see, for example, Fawcett & Markson 2010-a, 2010-b; Olson & Spelke 2008; Vaish, Missana, & Tomasello, in press). In particular, children were introduced to a protagonist who needed the help of others in five tasks. For example, one task required retrieving a displayed item while another task involved carrying a heavy object. In every situation, two friends of the protagonist were present. In each case, only one of the friends was able to provide the help as only he/she was, for example, tall or strong enough.

To examine children's ability to choose the adequate person for help, we assessed their judgments of which of the friends the actor would ask for help. Furthermore, children were asked to justify their choice. A comparison between both measures would be informative with respect to the possible social-cognitive mechanisms that underlie children's developing ability to evaluate others' action capabilities. If children were able to choose correctly the adequate helper before they were able to justify their choice, this would suggest that their ability to evaluate others' action capabilities is initially more practical form of

knowledge that over developmental time becomes explicated in conceptual or discursive knowledge (Karmiloff-Smith, 1992; for detailed epistemological analyses of this account see Brandom, 1994; Habermas, 1985). However, if there was no developmental lag between the two measures, this would indicate that even at its developmental origin this knowledge is of conceptual nature (for a similar discussion concerning the cognitive mechanisms behind children's selective learning from other people see Koenig & Jaswal, in press; Lucas & Lewis, 2010). As it has been suggested that children from 3 years on are able to estimate other people's reachability space (Rochat, 1995), we investigated 2.5-, 3.5- and 5-year-old children.

2. Method

2.1 Participants

The final sample of the study consisted of 36 children, including twelve 2.5-year-old children (*range*: 2 years, 5.8 months to 2 years, 11.3 months; 6 boys), twelve 3.5-year-old children (*range*: 3 years, 5.2 months to 3 years, 10.7 months; 7 boys), and twelve 5-year-old children (*range*: 4 years, 6.2 months to 5 years, 4.2 months; 7 boys). The participants were recruited from a database of parents who volunteered to participate in psychological studies, all being native English speakers from heterogeneous socioeconomic background in Nova Scotia, Canada. Informed consent for participation was given by the children's parents. The families received a certificate for their visit.

2.2 Tasks and Materials

Children were presented with ten dolls over the course of the five tasks (see Figure 1). One doll represented the protagonist (Piglet). In every task two dolls represented friends of Piglet. The tasks were performed by one experimenter and varied in the type of problem that the protagonist encountered and the type of action capability required. Action capability was varied between the two dolls that represented Piglet's friends. Every task started with Piglet appearing in the scene, greeting his friends, and subsequently either trying, but failing to perform an action or announcing that he was not able to perform the action. After admitting that he could not perform the action himself, he articulated that he could ask one of his friends for help. He subsequently approached his friends. The experimenter asked the child to show him, which of his two friends Piglet would ask for help: "What do you think: Whom of

his friends is Piglet going to ask for help?" If the child did not react, the question was repeated in another wording: "Who is Piglet going to ask for help?" If the child made the correct choice, he or she was further asked to justify, why Piglet would ask this friend and not the other. The order of tasks was balanced among participants with the exception of the balcony task and the dog's house task; as both tasks involved the same dolls, they were always presented after each other.



Figure 1. The figure displays the stimuli used in the experiment. The doll in the front shows the main protagonist Piglet. The dolls behind Piglet show (from left to right) the two male dolls used in the basket task, the two princesses used in the balcony and the dog's house task, the two male dolls used in the wall task, and the two girls used in the letter task. The doll on the top of the toy house is Elmo who has been employed for the balcony and the dog's house task.

The balcony task (Out of reach)

A tall and a small princess were standing in front of a toy house. Piglet entered the scene with two objects in his hand. He greeted the princesses and started playing with his objects. Suddenly, another actor (Elmo) showed up, took one of the objects, and put it on the balcony

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of the toy house. Piglet expressed sadness that the object was gone and tried to get it back. He reached for it, but was not tall enough to get it. He admitted that he could not get it and might need the help of one of his friends.

The dog's house task (Small hole)

The same princesses were standing in front of the house. Piglet continued to play with his items. Elmo showed up again, took the other object, and put it into the dog's house. Piglet expressed sadness that the object was gone and tried to get it back. He tried to get into the dog's house, but was not small enough to enter it. He admitted that he could not get his object and might need the help of one of his friends.

The basket task (Two hands)

Two men were standing in front of the house. The dolls were identical apart from the fact that one had a sling around his arm and neck as if he had broken his arm. Piglet entered by jumping onto the table carrying a basket with two handles. He greeted the men and asked them how they have been doing. Whereas one expressed that he is enjoying the day, the other said that he had broken his arm and cannot do anything with it. Piglet then picked up the basket again, taking each handle with one hand while verbalizing that he needs one hand for each handle. He carried it around, but stopped after a couple of seconds and announced that the basket is very heavy. He admitted that he could not carry it and might need some help from one of his friends.

The letter task (Reading task)

Two girls were standing in front of the house. The dolls were identical besides the fact that one had a blindfold over her eyes. Piglet entered the table with a piece of paper in his hand. He greeted the girls and asked what they were doing. The girl who was not blindfolded announced that she had blindfolded her sister to play a game with her. She danced around her sister and asked her, if she could see her. The blindfolded sister responded that she could not. Thereupon, the girl who was not blindfolded asked Piglet, if he wanted to join, but Piglet declined. He told the girls that he had just received a letter from his mother and would like to know, what is written on this letter. He admitted that he could not read it and might need the help of one of his friends.

The wall task (Heavy object)

Two men were standing in front of the house. Both dolls showed shirtless men, of which one was clearly more muscular than the other. Piglet entered the scene. He greeted the men and asked them how they have been doing. The less muscular man responded that he was enjoying the day, whereas the other responded that he has recently won a prize for being the strongest man in Canada and invited Piglet to feel his muscles. Piglet felt his muscles and then announced that he has to get some work done, in particular, that he has to move a wall. When repeatedly trying to move it, the wall moved only slightly. Piglet admitted that he cannot move it and might need some help from one of his friends.

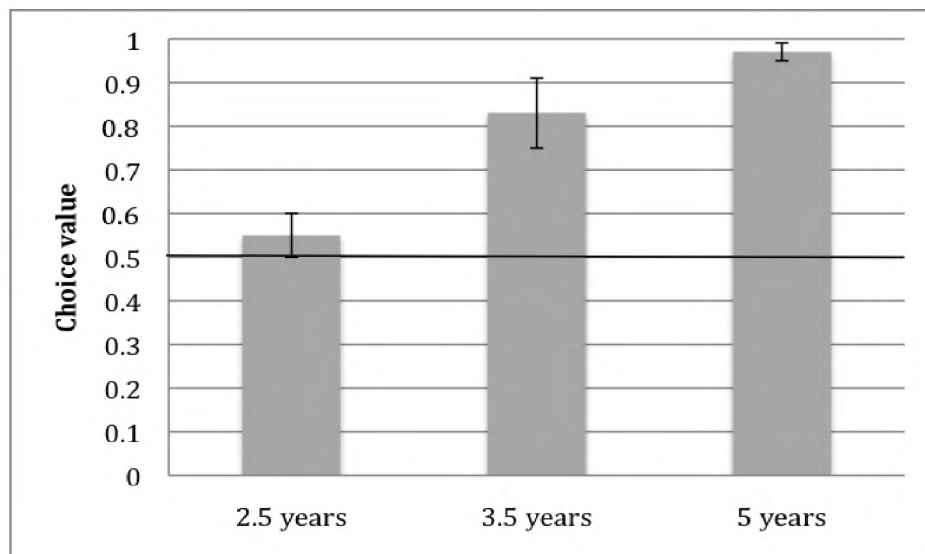
2.3 Coding and Analysis

All sessions were videotaped and coded by the first author of the study. A research assistant who was unaware of the hypothesis of the study coded a random sample of 33% of each age group's data. First, we coded which of the two friends were chosen by participants as the one whom Piglet will ask for help. A value of 1 was assigned for every task if participants choose the appropriate doll (i.e., the taller doll for retrieving an object from the balcony) by either verbally indicating, grasping or clearly pointing (to) this doll. A value of 0 was assigned for the incorrect choice. Subsequently, the results were summed per child and divided by the number of tasks to yield a total correct score (choice value). A correlational analysis (based on the choice values per child) showed a perfect agreement between both raters, $r=1$, $p<0.001$. Data were analyzed for age effects employing a univariate analysis of variance (ANOVA) with the between-subjects factor age group (2.5 years, 3.5 years, 5 years). Furthermore, we employed independent samples t-tests for every group (corrected by the Bonferroni procedure) to assess if children's performance differed from chance level.

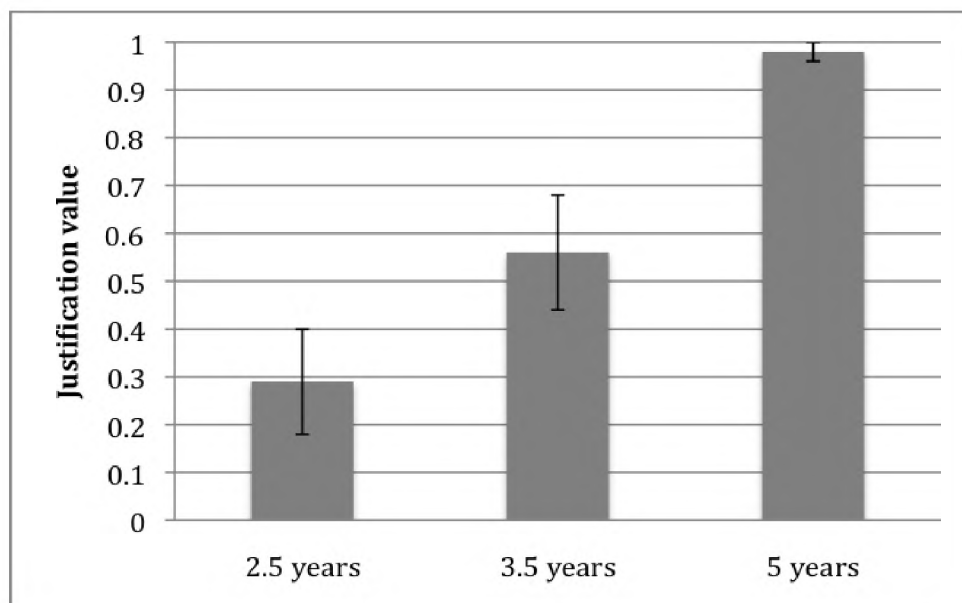
Second, we analyzed the justifications of all trials, in which the participants had chosen the correct doll. The justifications were coded as either being appropriate or not (see Figure 2B). An appropriate answer was defined as being relevant and precise. That means that an appropriate answer must point to the information that is relevant for the situation and it must be precise with respect to this important person characteristic (e.g., when in the *balcony task* the participant answered: "this doll is taller than the other", "she is tall enough"). If the child's answer was not appropriate, the answer was further coded as being only relevant but not precise (e.g., "because he needs help", "because she can get the candle"), only precise but not relevant (e.g., "because she is a princess", "because he wears

pants”), explicit statement of ignorance (e.g., “I don’t know”), something else (e.g., “Look. There.”) or no answer given (see Figure 2C). A justification value was defined for each participant based on the proportion of trials, in which a relevant and precise answer was given. An interrater reliability analysis using the Kappa statistic was performed to determine consistency among raters. The analysis yielded a good level of agreement ($k = 0.80$, $p < 0.001$). Data were analyzed employing an ANOVA with the between-subjects factor age group (2.5 years, 3.5 years, 5 years).

A)



B)



C)

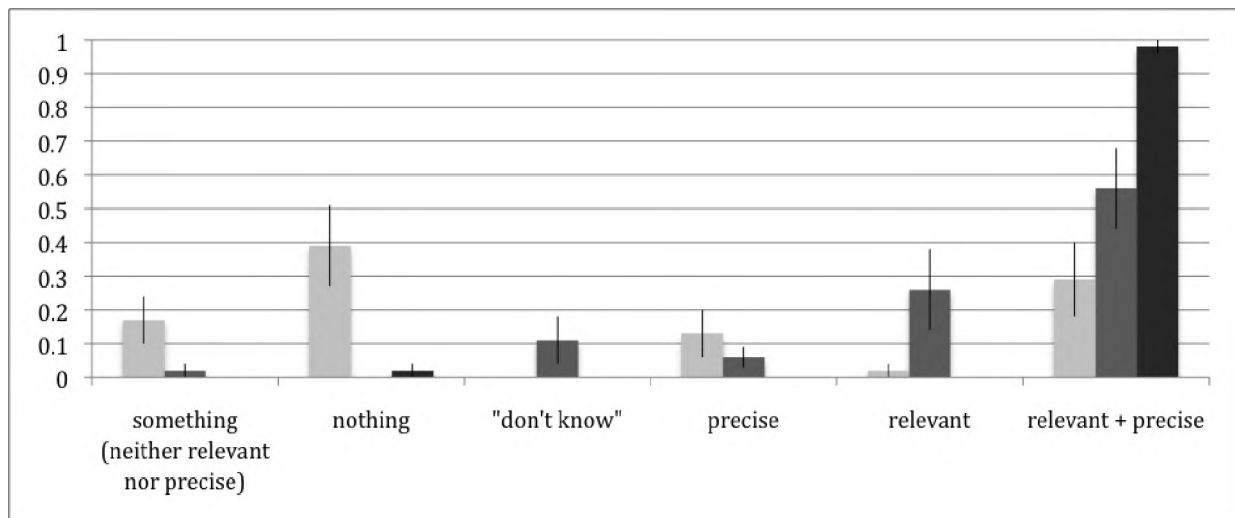


Figure 2. Figure A shows the average choice value (i.e., average correct choice) for the 2.5-, 3.5-, and 5-year-old children. Error bars indicate standard error of the means. The bold horizontal line emphasizes the 50%-value (i.e., chance performance). Figure B shows the average justification value for the 2.5-, 3.5-, and 5-year-old children. Error bars indicate standard error of the means. Figure C gives a more detailed overview over the different categories of answers provided by the 2.5-, 3.5-, and 5-year-old children in the justification question.

| | Balcony task | Dog's house task | Basket task | Letter task | Wall task |
|------------------|--------------|------------------|-------------|-------------|-----------|
| 2.5 years | 33% | 67% | 67% | 58% | 50% |
| 3.5 years | 83% | 67% | 83% | 92% | 92% |
| 5 years | 100% | 100% | 100% | 92% | 100% |

Table 1. Table 1 displays the results by age group (rows) and task (columns). Each cell shows the average performance of children of a particular age group in a task.

3. Results

Figure 2A displays the averages of the choice values per age group. A preliminary analysis yielded no significant differences between tasks (Cochran's $Q(4)=2.250$, $p=0.69$; see Table 1). The analysis yielded a significant effect of age group, $F(2, 33)=15.152$, $p<.001$, $\eta_p^2=0.48$.

Post-hoc t-tests revealed that the performances of the 2.5-year-olds differed significantly from the 3.5- and 5-year-olds, $t(22)=3.081$, $p<0.01$ and $t(22)=7.601$, $p<0.001$, respectively, whereas no significant differences were found between these age groups, $t(22)=1.658$, $p=0.11$. The t-tests against chance level showed that the performances of the 3.5-year-olds, $t(11)=4.318$, $p<0.005$, and of the 5-year-olds differed from chance, $t(11)=20.765$, $p<0.001$, but the performance of the 2.5-year-olds⁴, did not $t(11)=1.000$, $p=0.34$.

Next, we analyzed the justification values (i.e. the frequency of relevant and precise justifications in trials, in which participants had chosen the correct doll). The analysis of the justification values revealed a significant effect of age group, $F(2, 33)=13.054$, $p<0.001$, $\eta_p^2=0.44$. Post-hoc t-tests showed that the performance of the 5-year-olds ($M=97.9\%$, $SD=7.2$) differed significantly from the 3.5- and 2.5-year-olds ($M=56.1\%$, $SD=41.1$ and $M=29.2\%$, $SD=39.6$, respectively), $t(22)=3.476$, $p<0.01$ and $t(22)=5.910$, $p<0.001$, respectively, whereas no significant differences was found between the latter age groups, $t(22)=1.634$, $p=0.12$.

4. Discussion

The goal of this study was to assess the development of children's ability to take other person's action capabilities in a helping situation into account. To this end, 2.5-, 3.5-, and 5-year-old children observed a protagonist who needed the help of friends to accomplish several tasks. Typically, only one of the friends was physically able to provide the help. Our results showed a significant developmental effect with children in the two older groups performing significantly better than those in the youngest group. Furthermore, children in the two older groups chose the appropriate character at levels well above chance, whereas the performance of the younger children did not differ from chance. We may infer therefore that the 3.5- and 5-year-old, but not the 2.5-year-old children were able to choose the appropriate doll for help. We interpret our findings as evidence that children's ability to consider others' action capabilities in helping situations develops at least around 3 years of age.

⁴ To ensure that 2.5-year-olds' failure was not merely due to the verbal demands of the task, we randomly asked eight participants in one of the tasks, in which they failed to choose the appropriate doll, to show what the chosen doll has to do to help Piglet. Seven out of the eight participants correctly initiated the appropriate action (e.g., choosing the weaker doll in the wall task to move the heavy object). This suggests that the participants understood the task.

Chapter 5: CHILDREN'S UNDERSTANDING OF OTHERS' ACTION CAPABILITIES

In the following, we will first discuss the relation of our findings to the literature on selective social learning in preschool children. Then, we will discuss the impact of the task on children's performance and the possible mechanisms that could subserve children's performance in the choice and the justification measure. Finally, the implications of our results for theories on the development of action perception and joint actions are considered.

Our results add to recent findings on children's selective reliance on other people in social learning tasks (e.g., Birch, Vauthier, & Bloom, 2008; Clement, Koenig, & Harris, 2004; Pasquini et al., 2007; Sobel & Corriveau, 2010; Sodian, Thoermer, & Dietrich, 2006). In particular, it has been found that 3- to 4-year-old children monitor others' past performances and selectively learned novel object labels from the previously more accurate person (Koenig et al. 2004). Furthermore, selective learning is not restricted to language acquisition. Birch and colleagues (2008) provided evidence that preschool children also selectively relied on a previously accurate person to acquire knowledge about a novel object's function. Our results extend these findings to the realm of physical action capabilities by demonstrating that by 3.5 years of age children take physical action capabilities into account when assessing situations, in which someone needs others' help.

It should be noted that we employed a third-person approach to study children's developing ability to evaluate others' physical action capabilities. Employing such an approach enabled us to examine children's performances across a number of diverse tasks that assessed different person characteristics. This allows us to rule out that the developmental trends in our results are restricted to one kind of physical action capability (e.g., strength but not height). However, even though developmental research on children's social-cognitive development has successfully used tasks that employed dolls (e.g., Fawcett and Markson, 2010-a) or photos (Shutts, Banaji, & Spelke, 2010) to depict human actors, it would be interesting to explore the impact of different kind of tasks on children's ability to evaluate others' action capabilities. In particular, future research is necessary to investigate whether children would show earlier success in a task, in which the children need to seek help for themselves and can choose among possible helpers whose action capabilities differ. Notwithstanding this possibility, our results point to an important developmental lag between children's ability to choose the appropriate person for help and to justify their choices.

The present finding raises the question of how this ability develops. Different mechanisms have been suggested to affect and subserve the processing of other's actions.

Within a motor simulation account it has been proposed that observers use their own action experiences and action capabilities to process information about other people's actions (Wilson & Knoblich, 2005). Although previous research with adults and young children has provided evidence for an impact of one's own action capabilities on their action perception (e.g., Eskenazi, Grosjean, Humphreys, & Knoblich, 2009; Paulus, Hunnius, Vissers, & Bekkering, *in press-c*), it is unlikely that this mechanism can be the main cause for children's improvement in the perception of others' action capabilities as there are no obvious motor developments around 3 years of age that could affect the perception of such different properties as strength and height, or the use of one or both hands.

In particular, it has been argued that "action understanding and prediction may reflect a situated, online sensitivity to optical information, especially in the case of predicting possibilities for action" (Ramenzoni et al., 2008, p. 1060). Based on these findings one could argue that, for example, the affordance for grasping the object on the balcony in one of our tasks was different for the tall compared to the small person. The fact that only 3.5-, but not 2.5-year-old children were able to choose the appropriate helper could thus indicate that the ability to perceive the affordances of others' actions develops around the fourth year of life. Is this a reasonable explanation given the findings within the object perception literature that already infants are able to perceive the action affordances for different objects (e.g., Paulus & Hauf, *in press*; Gibson & Pick, 2000)? Note that our task differs from studies on infants' object perception, in that our study did not require the perception of the actions the objects afforded for the children themselves, but rather the actions the objects afforded for another person. Furthermore, as they had to choose amongst two possible helpers, they had to compare the actions afforded by the objects for two different persons. Such a comparison likely demands more cognitive resources and thus develops later than the direct perception of object affordances. However, our results do not directly point to cognitive mechanism underlying children's behavior in the choice task. Further research is necessary to investigate the impact of motor resonance and affordance perception on children's perception of other people's action capabilities.

The question of the cognitive mechanisms relates also to a currently debated topic in the literature on children's selective learning (cf. Koenig & Jaswal, *in press*; Koenig & Woodward, 2010; Lucas & Lewis, 2010). It has been discussed that children's reliance on a more reliable actor in a selective social learning task might rather be due to a general preference for this actor on basis of one particular person characteristic (e.g., a halo effect)

than due to an expectation that this actor has specific knowledge that another actor does not have (Koenig & Jaswal, in press). Applied to our study one could ask if children's performance might be due to a diffuse knowledge that, for example, taller is better and that they therefore choose the taller doll in the balcony task. Whereas this explanation cannot be excluded for all of our tasks, a comparison of the balcony task and the dog's house task suggest that this is not the case. In particular, for both tasks the same dolls were used (i.e. tall and small princess). Yet, in one task the tall princess, in the other task the small princess was the more appropriate helper. The fact that the majority of the 3.5-yr-old children and all of the 5-yr-old children chose the appropriate doll in each task suggests that their choices were not subserved by a general preference for the tall or the small doll, but rather by more differentiated knowledge about who was more appropriate for which task. Our findings are thus in line with findings by Koenig and Jaswal (in press) that children have a specific expectation for which knowledge domain someone is expert in by showing that they also have a specific expectation of what a person can or cannot do.

Importantly, further insight into the nature of children's developing understanding of other people's action capabilities is provided by a comparison between the choice data and the justification data. Even though the 3.5- and 5-year-olds performed at approximately the same level in terms of choices alone, our analysis revealed profound age differences in their ability to justify their choices. Justifying a correct choice means explicating implicit or practical knowledge in a discursive format (Karmiloff-Smith, 1992; see also Brandom, 1994;), a format that is open to reflection and that allows assessment of the validity of reasons (cf. Habermas, 1985). The fact that the younger children were able to adequately judge others' action capabilities without necessarily being able to justify their choice is thus not only in line with other studies showing that children's justifications lag their judgments in development (e.g., Thomas & Horton, 1997; for a controversial discussion of which criteria to use in the attribution of knowledge to a child see also van der Maas, Jansen, & Raijmakers, 2004; Smith, 1992). It also supports the theoretical notion that perceiving the relation between an actor and the possible targets of his action has to be conceived of being practical (or implicit) knowledge that is not reflected in conceptual terms.

However, our research leaves open the question of what mechanisms subserve the developing ability to justify one's own actions. It has been argued that children's embedding in social discourses plays a fundamental role in their cognitive development (Nelson, 2007; Vygotsky, 1991). Support for this theoretical approach comes from studies that show

relations between mothers' and their children's use of justifications in disputes (Dunn & Munn, 1987) or the impact of training in exploratory talk on subsequent reasoning in school children (Wegerif, Mercer, & Dawes, 1999). Accordingly, children's ability to explicate their knowledge could be promoted by their progressive embedding in discourses in which they are asked to justify their actions. However, it remains an open question whether children's developing justification abilities are due to a general development in reasoning skills (i.e. domain-independent) or restricted to a particular knowledge domain (see Sodian & Bullock, 2008). Furthermore, in this study we did not control for general language or cognitive abilities. Even though our results indicate that the 3.5-year-old children were able to understand the question and to provide relevant answers, suggesting that their worse performances in the justification task were not due to lacking language skills, the precise impact of children's language skills on their task performance remains an open question. Future research is necessary to directly examine the development of justification skills in preschool children. Whatever the precise developmental origin of this ability may be, our results provide clear evidence that from 5 years on children are able to explicitly reason about another person's action capabilities when they have to decide whom to ask for help.

Our results have implications for research on children's developing action understanding and their ability to engage in successful joint actions with others. Whereas research has shown that infants from their first year of life use information about another agent's previous behavior and own action experiences to predict or understand others' actions (Paulus et al. in press-a; Sommerville & Woodward 2005), it has remained an open question how children process others' action capabilities, i.e. action-related information when no ongoing action is presented. Our finding that 3.5-, but not 2.5-year-old children are able to do so indicates that having an understanding of others' action capabilities is a more complex computation (i.e. a rather abstract evaluation of what somebody could do, if he would act in a certain situation) than predicting, for example, the goal of an ongoing action. Our findings are therefore informative for theories on the development of social understanding (e.g., Barresi & Moore, 1996).

Our results also inform current research on the development of children's developing ability to engage in successful joint actions. To effectively collaborate with other people in joint activities, one must be able to take another person's physical action capabilities into account (Sebanz et al., 2006). Our findings provide evidence that this essential social-cognitive ability for successful joint action develops around 3 years of age. Together with

recent studies showing that other crucial social-cognitive abilities for the ability to engage in successful joint actions develop around 3 years of life (forming joint commitment: Gräfenhain, Behne, Carpenter, & Tomasello, 2009; action coordination: Meyer, Bekkering, Paulus, & Hunnius, 2010) our results suggest thus that by approximately 3 years of age children have developed the necessary social-cognitive prerequisites to successfully cooperate with others.

Taken together, the present study extends current knowledge by showing that children from at least 3.5 years of age on are able to perceive others' physical action capabilities and that 5-year-olds, but not younger children are able to adequately reason about others' action capabilities.

Chapter 6

Imitation in infancy: Rational or motor resonance?



Based on:

Paulus, M., Hunnius, S., Vissers, M., & Bekkering, H. (in press). Imitation in infancy: Rational or motor resonance? *Child Development*.

Abstract

The present study investigates the contribution of two mechanisms to imitation in infancy. The principle of rational action suggests that infants normatively evaluate the efficiency of observed actions. In contrast, it has been proposed that motor resonance (i.e. the mapping of others' actions onto one's own motor repertoire) plays a central role in imitation. We tested 14-month-old infants ($n=95$) in five conditions and manipulated the extent to which the observed actions could be matched onto the infants' own motor repertoire as well as whether the observed behavior appeared to be efficient. The results suggest that motor resonance plays a more central role in imitation in infancy than does a rational evaluation of the observed action.

1. Introduction

One of the reasons for *homo sapiens*' success is the ability to transmit knowledge from one generation to the next (Gould, 1979). This transmission is often organized formally in specialized institutions like schools and relies to a large extent on language as the medium of transmission (Habermas, 1985). However, cultural knowledge is transferred also in a non-verbal way and even at an age before language has fully developed. Infants acquire new behaviors, the basics of their own language, and knowledge about the use of objects partly by imitating others. Imitation of observed actions therefore plays an important role in the socialization of the child and the acquisition of cultural knowledge (Byrne & Russon, 1998; Tomasello, Carpenter, Call, Behne, & Moll, 2005).

Studying early imitation offers unique possibilities to investigate infants' perception and understanding of other people's actions (Elsner, 2007). An intriguing example has been provided by Meltzoff (1995): Infants who observed an adult trying but failing to perform an action imitated the action with successful goal attainment. The infants' imitation behavior revealed that they perceived the adult's action as goal-directed although they never fully observed it. Subsequently, numerous studies have shown that infants' and children's imitation of actions is indeed goal-directed (e.g., Bekkering, Wohlschläger, & Gattis, 2000; Gleissner, Meltzoff, & Bekkering, 2000; Hamlin, Hallinan, & Woodward, 2008).

The present study aims to investigate the mechanisms which subserve infants' imitation of actions in more detail. Amongst others (see, for an overview, Meltzoff & Prinz, 2002) two different mechanisms have been proposed to underlie imitation in infancy and have recently received considerable attention: teleological reasoning, and direct motor matching, usually labeled motor resonance.

The first approach, the notion of teleological reasoning, assumes that infants normatively evaluate an action by applying the principle of rational action (Gergely & Csibra, 2003). Consequently, they understand and predict others' action goals by observing the actions, under the assumption that the action is efficient. Furthermore, given a particular goal, the principle of rational action allows assessment of the rationality of the means chosen to perform the action (Csibra & Gergely, 2007). Support for this view comes to a large extent from studies of infants' action perception using habituation procedures (e.g., Csibra, Gergely,

Bíró, Koós, & Brockbank, 1999; Gergely, Nádasdy, Csibra, & Bíró, 1995; Sodian, Schoeppner, & Metz, 2004).

The second mechanism, motor resonance (e.g., Wilson & Knoblich, 2005), focuses on well-established findings that the observation of others' actions facilitates the execution of the same motor act (e.g., Fadiga, Fogassi, Pavesi, & Rizzolatti, 1995; Brass, Bekkering, Wohlschläger, & Prinz, 2000), which suggests that action perception and action production share a common representational format (Prinz, 1997). Moreover, action perception and action execution have been shown to involve overlapping brain areas (Iacoboni et al., 1999; Gazzola & Keysers, 2009), and it has been suggested that the mirror neuron system is at the basis of this capacity to match observed actions onto one's own motor repertoire (e.g., Rizzolatti & Craighero, 2004). Infants' ability to relate an observed movement on their own action system might thus be based on such a mapping mechanism (Hauf & Prinz, 2005; Meltzoff, 2007). The possibility to match another person's action onto one's own motor repertoire is especially important within an ideomotor approach to action production and imitation (Wohlschläger, Gattis, & Bekkering, 2003). The ideomotor principles supposes that actions are represented in terms of their effects so that when attempting to achieve an effect the corresponding action will be activated (bidirectional action-effect associations; Hommel, Müsseler, Aschersleben, & Prinz, 2001). Accordingly, to be able to imitate an observed action infants need to match this action onto their own motor repertoire during observation and connect it to their representation of the action's effect. A bidirectional action-effect association is built and infants are subsequently able to retrieve the appropriate action when they want to reproduce the effect (see Hommel, 2009).

Within the last years research has yielded evidence that infants' action perception is influenced by their own action capabilities and action experiences (e.g., Hauf, Aschersleben, & Prinz, 2007; Sommerville & Woodward, 2005; van Elk, van Schie, Hunnius, Vesper, & Bekkering, 2008; for an overview see Hauf, 2007). Van Elk and colleagues (2008), for example, showed that an infant's experience with crawling is directly related to the amount of motor resonance during observation of the same action. Sommerville and Woodward (2005) provided evidence that 10-month-old infants tend to perceive other people's means-end behavior as goal-directed if they themselves are able to perform the same actions. Altogether, the above-mentioned findings of an impact of infants' own action experiences and action capabilities on their action perception support the notion that motor resonance is an important factor of action perception in infancy.

Chapter 6: IMITATION IN INFANCY: RATIONAL OR MOTOR RESONANCE?

Recently, however, the results of a widely noticed study seemed to support the role of teleological reasoning in infants' imitation (Gergely, Bekkering, & Kiraly, 2002). In this study, two groups of 14-month-old infants watched an adult model acting on a light box. The adult was sitting at a table with a black box in front of her. A lamp was mounted onto the box, which could be switched on by touching its upper part. The adult leant forward and touched the lamp with her forehead, thereby causing a salient light effect. In one condition the adult was pretending to be cold, holding a blanket with her hands (*hands occupied* condition) when performing the head touch, while in a second condition her hands were free and the blanket was hanging loosely around her shoulders (*hands free* condition). When confronted with the lamp themselves one week later, more infants from the *hands free* condition performed the head touch than did infants from the *hands occupied* condition. The authors concluded that infants applied the efficiency principle of rational action and assessed the head touch in the *hands occupied* condition as caused by the situational constraints, as the actor had to use her head because her hands were occupied by holding the blanket. In the *hands free* condition, however, since the model appeared to use her head deliberately as her hands were not occupied, the infants reproduced the head touch. This finding, which has been interpreted as evidence that imitation in infancy is guided by a rational evaluation of situational constraints and an attribution of subjective reasons to another person, has inspired a new line of research. For instance, it has been reported that younger infants (Zmyj, Daum, & Aschersleben, 2009), apes and monkeys (Buttelmann, Carpenter, Call, & Tomasello, 2007, 2008; Wood, Glynn, Phillips, & Hauser, 2007) as well as dogs (Range, Viranyi, & Huber, 2007) also imitate rationally. In many of these studies a version similar to the head touch paradigm was used in which a lamp could be switched on by touching it with a body part other than the hands (e.g., Buttelmann et al., 2007; Wood et al., 2007; Zmyj et al., 2009).

A critical, but often neglected finding of studies using the head touch paradigm is that almost all infants – even in the *hands free* condition – first use their hands to turn on the light, before they perform the head action (e.g., Gergely et al., 2002; Zmyj et al., 2009). The question arises how infants' use of their head to turn on the lamp can be viewed as a result of their rational reasoning as in most cases they have just experienced that the lamp can equally well be switched on using the hands. Moreover, theoretical analyses of infants' behavior have repeatedly pointed out that infants' performance in certain tasks, albeit superficially similar to adults' behavior, is not necessarily subserved by the same mechanisms (see the argument by analogy; cf. Moore, 2006). This is particularly important for the claim that infants imitate

rationally. As such sophisticated cognitive abilities are otherwise not evident in this age group (e.g., counterfactual reasoning; Rafetseder, Cristi-Vargas, & Perner, 2010; see also Perner, 1991) one might wonder if infants' imitation in the head touch task is indeed subserved by an evaluation of the action's efficiency and not by another mechanism. Additionally, key epistemological arguments have been provided that the ability to reflect rationally about other people's actions is closely linked to the ability to use language (Brandom, 1994; Davidson, 1982; Habermas, 1985). Considering these issues, more research is needed before teleological reasoning can be accepted as a major mechanism subserving infants' imitative behavior in the head touch paradigm.

Importantly, in the experiment by Gergely et al. (2002) there are possibly important differences in the model's actions between the two conditions: In the *hands free* condition the model put her hands on the table when performing the head touch, while in the *hands occupied* condition her arms were folded across her chest. Note that when infants perform a head touch themselves, they put their hands on the table next to the lamp, probably to be able to maintain a stable position. Interestingly, this action matches closely the movement the adult modeled in the *hands free* but not in the *hands occupied* condition. In other words, the action of the model when performing the head touch can be matched to a larger extent in the *hands free* condition than in the *hands occupied* condition. Following the notions of ideomotor theory and motor resonance this should enable infants to relate the observed head touch action to the light effect in the *hands free* condition to a larger extent than in the *hands occupied* condition. Consequently, when given the lamp, infants in the hands free condition were more likely to activate the motor program of turning on the lamp with the head.

Our study contrasts the role of rational reasoning and of motor resonance in the head touch paradigm in more detail. We introduced three new conditions besides the two classical ones used in the Gergely et al. (2002) study to separately examine both mechanisms. The new *button* condition was comparable to the *hands occupied* condition, as the model had a blanket wrapped around her shoulders which covered her upper body. However, this time the blanket was held by a salient button so that the model was able to use her hands to switch on the light. Following the rational imitation approach a high number of infants should use their head to turn on the lamp in the *button* condition, since the model could have used her hands, but chose freely to turn on the lamp with her head. Following the motor resonance approach, infrequent head touches are expected as this action did not match the infants' own motor repertoire. The second new condition, *hands up*, resembled the *hands free* condition with the

difference that this time the model raised her hands instead of putting them next to the lamp. By doing so the head touch action did not match with any action in the infants' motor repertoire since infants cannot raise their arms and lean forward at the same time without being held by somebody. Observing this action should thus activate the infant's motor system to a much lesser extent and should lead to a low number of infants turning on the lamp with the head. According to the rational imitation approach, however, it is expected that infants would use their heads to turn on the lamp due the fact that the model obviously voluntarily used her head to turn on the lamp. The third new condition, *balls*, resembled the *hands free* condition with the difference that the model's hands were occupied by two foam balls with which she had played before modeling the head touch. Following the rational approach to imitation, infrequent head touches are expected since the model's hands were restricted. However, according to the motor resonance account, a large number of infants should perform the head action in this condition due to the matching of the observed action onto the infants' own motor repertoire. Note that for each of the three new conditions contradicting predictions were derived from the two theories whereas they made exact the same predictions for the original two conditions (see Figure 2A).

2. Method

2.1 Participants

Participants were 95 14-month-old infants ($M = 14$ months, 16 days; range 13;15 to 14;31; 50 boys). In particular, the final sample included 19 infants in the *hands free* condition ($M = 14$ months, 17 days; 9 boys), 19 infants in the *hands occupied* condition ($M = 14$ months, 18 days; 8 boys), 19 infants in the *button* condition ($M = 14$ months, 20 days; 9 boys), 19 infants in the *hands up* condition ($M = 14$ months, 22 days; 12 boys), and 19 infants in the *balls* condition ($M = 14$ months, 12 days; 12 boys). An additional 32 infants did not complete the experiment due to inattentiveness or fussiness ($n=21$), interference by the parent ($n=5$), or a procedural ($n=3$) or technical ($n=3$) error. The infants who were inattentive or fussy were equally distributed across the experimental conditions. The participants were healthy, full-term infants without any pre- or perinatal complications. They were recruited from a database of parents who expressed interest in participating in research with their child. Infants were primarily white and from middle class families, living in a medium-sized European city. The infants' parents gave informed consent for participation of their child in the study and were

given a baby book or monetary compensation for their visit.

2.2 Setting

The light box consisted of a lamp (diameter 13 cm) which was mounted onto a black box (27 x 19 x 5.5 cm). The box was filled with lead so that the infants were unable to move it. The experiment took place in an experimental booth to minimize distraction for the child. During the experiment, the infants were sitting on their parent's lap. The experimenter and the parent and infant were sitting at a table, which had a rectangular recess on the side at which the parent and infant were seated. The blankets used in the experiment were made of blue fleece (130 x 158 cm). The blanket for the condition *button* had a clearly visible red button (diameter 8 cm) attached to it, and a buttonhole had been made for the button. The two softballs (diameter 7 cm) for the condition *balls* consisted out of soft, yellow foam. Two cameras were used to record the infant's as well as the experimenter's behavior during the experiment.

2.3 Procedure

Infants were randomly assigned to one of the five conditions. Before starting the experiment, the experimenter took time to let the infant get used to the testing room. Parents were given instructions which contained information about the way the infant had to be positioned on the lap and how to behave during the experiment. In particular, they were asked not to interact with their child during the experiment and to remain silent with a neutral, but friendly facial expression. No details about the scientific question of the experiment were given beforehand. When parent and infant were seated properly, the experimenter left the experimental booth for a few moments. Light was dimmed to a moderate level in order to make the light of the light-box more salient. The experimenter grasped the blanket and re-entered the booth, and modelled the action sequence which belonged to the specific condition.

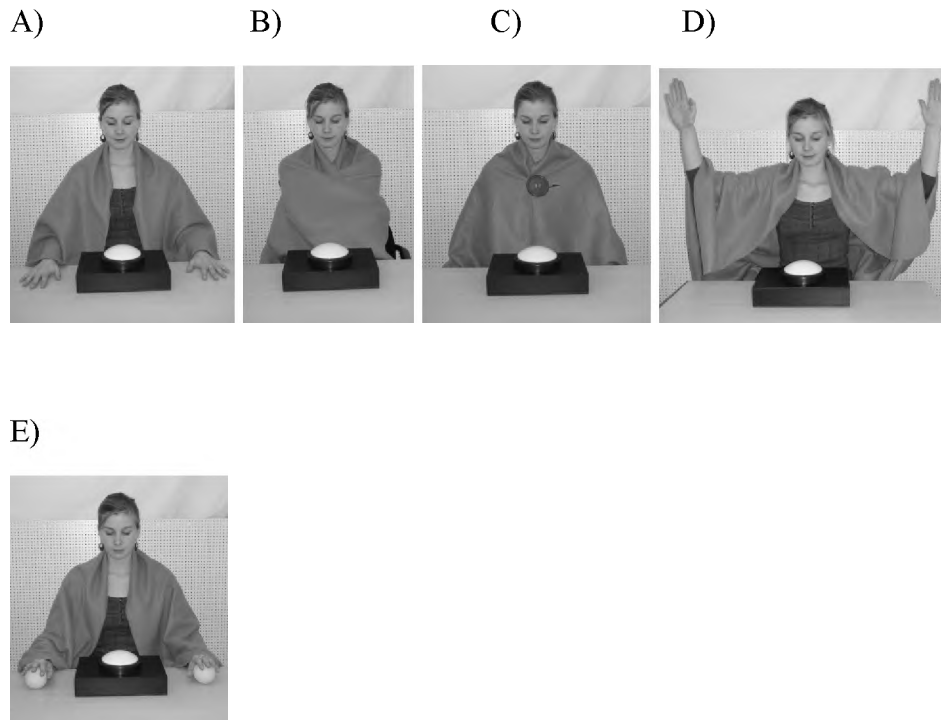


Figure 1. Pictures of the five experimental conditions (A hands free, B hands occupied, C button, D hands up, E balls) showing the model's position before performing the head touch.

In all conditions the model entered the experimental booth and made sure that the infant paid attention to her. In the *hands free* condition, she placed the blanket around her shoulders. To make sure that the infant perceived that her hands were free, she first rubbed her hands and then grasped her chair and moved it a few centimeters. Then she sat down and put her hands next to the lamp (see Figure 1 for the different positions of the model). She made sure to have the infant's attention by calling his or her name and saying 'Look what I am going to do!'. Then, the model turned on the lamp using her forehead and returned to the initial upright position. The head touch was modeled four times. In between the head touches, the experimenter used the words 'Yes!' or 'Look!' in order to keep the infant focused. Additionally, she called the infant's name when the infant did not pay attention anymore. The experimenter's verbal and facial expressions were the same in all conditions. After having performed the action sequence, the experimenter let the blanket slip on the chair. Then she said 'Would you like to try as well?' to the infant and pushed the lamp across the table in front of the infant, stood up and left the experimental booth. After the experimenter left, the child was given 60 seconds to explore the lamp. When the 60 seconds had passed, the experimenter re-entered the booth and debriefed the parent.

The *hands occupied* condition differed from the *hands free* condition as the experimenter held the blanket up with her hands tightly wrapped around her shoulders. Instead of showing that she could use her hands she sat down at the table. The rest of the procedure was exactly the same as in the *hands free* condition with the only exception that the experimenter was holding up the blanket with her hands the whole time. On a perceptual level, the condition *button* was very similar to the *hands occupied* condition since the model's hands were covered by the blanket when performing the head touch. However, instead of wrapping the blanket around the shoulders and holding it with the hands, the experimenter used the button to fix it. She also demonstrated that her hands were free and she could use them, for example by moving the chair she was going to sit on. Furthermore, this ensured that infants were able to observe that the button held up the blanket even though the model was using her hands. The condition *hands up* was similar to the *hands free* condition and followed exactly the procedure of this condition. It differed only in the fact that the experimenter held her hands up in the air when performing the head touch instead of putting them on the table. In the condition *balls* the experimenter was wearing the blanket and demonstrated that the hands were not constrained as she did in the *hands free* condition. Next to the lamp, there were two softballs lying on the table. After taking a seat, the experimenter started to play with these softballs for approximately 8 seconds. The experimenter kept one softball in each hand and put her hands next to the lamp. Then, the procedure followed exactly the procedure of the *hands free* condition with the only difference that the experimenter was holding the two softballs in her hands during the experiment.

2.4 Coding

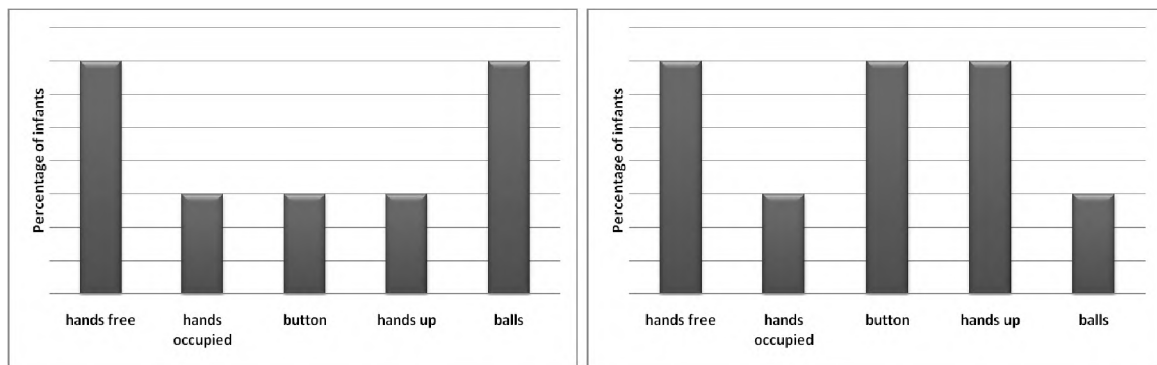
The first 60 seconds after the child was given the lamp and attended to it were coded (cf. Zmyj et al., 2009). An action was coded as a head touch when infants touched the lamp with their head or approached the lamp with their head to a distance of maximally 10 cm (cf. Gergely et al., 2002; Zmyj et al., 2009). Additionally, we coded how many of the infants who performed a head action only bent over the light to a distance of 10 cm from the lamp and how many touched the lamp with their head. To investigate the extent to which infants relied on their hands and heads, we coded which action infants performed first when switching on the lamp (hand or head action) and how often they turned on the lamp using their hands (hand touch) and heads. Chi square tests were carried out to examine differences in the number of infants performing a head touch between the conditions (e.g., Gergely et al., 2002). An

analysis of variance (ANOVA) with the factor condition was calculated to analyze the frequency of hand touches.

3. Results

As can be seen in Figure 2B, the number of infants who imitated the head action was different in the five conditions. As in the original experiment by Gergely et al. (2002) the head touch was imitated by more children in the condition *hands free* than in the condition *hands occupied*. 14 out of 19 infants (74%) performed the head touch in the condition *hands free* (11 with a full head touch), whereas in the condition *hands occupied* only 6 out of 19 infants (32%) imitated the head action (5 with a full head touch). A Chi Square Test revealed that the difference between the number of infants performing a head touch in these two conditions was significant, $\chi^2(1, 38) = 6.756, p < 0.01$.

A



B

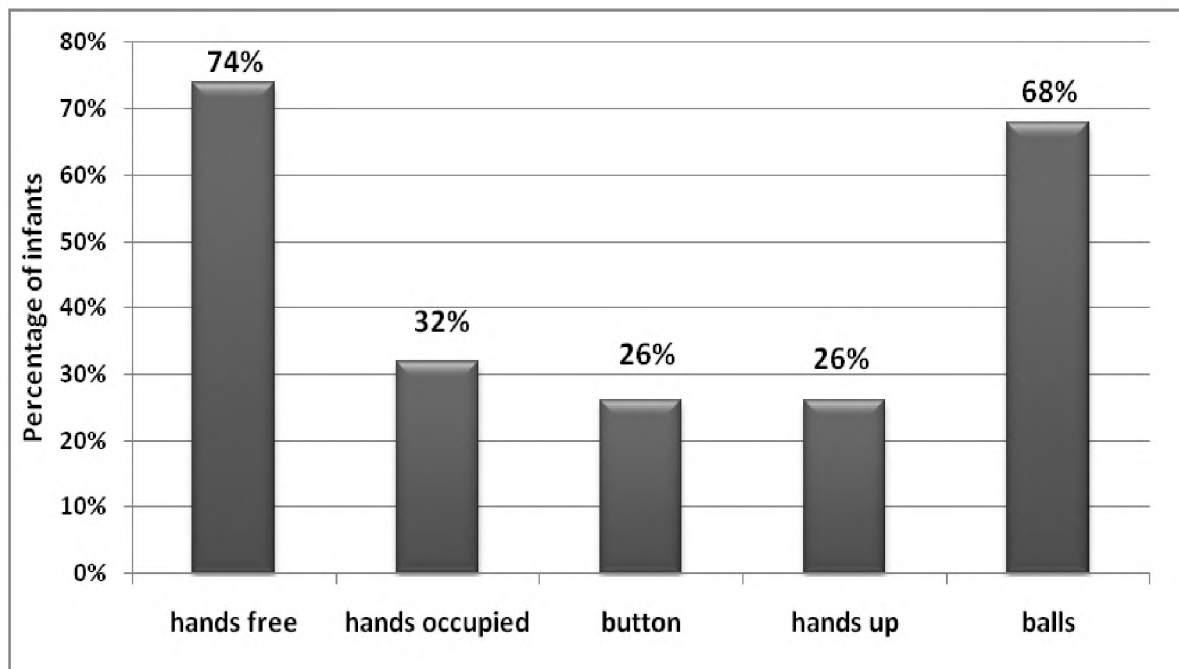


Figure 2. Figure A shows the predictions derived from the motor resonance account (left picture) and the teleological reasoning account (right picture). The y-axis represents the percentage of infants performing a head touch according to the predictions. Figure B shows the percentage of infants who performed a head touch in each of the five experimental conditions.

A further comparison between the condition *hands occupied* and the condition *button* was conducted to investigate whether the head touch was imitated with different frequencies in these two conditions. No significant difference was found between the *hands occupied* and the *button* condition, in which 5 out of 19 infants (4 with a full head touch) imitated the head action (26%), $\chi^2(1, 38)=0.128, p=0.72$. The number of infants imitating the head touch was

significantly larger in the condition *hands free* than in the condition *hands up*, in which 5 out of 19 infants (4 with a full head touch) imitated the head touch (26%), $\chi^2(1, 38)=8.526$, $p<0.01$. In the *balls* condition, 13 out of 19 infants (68%) imitated the head action (7 with a full head touch); this was not different from the *hands free* condition, $\chi^2(1, 38)=0.128$, $p=0.72$. A comparison between the number of infants performing a head touch in the conditions *balls* and *hands occupied* yielded a significant effect, $\chi^2(1, 38)=5.158$, $p<0.05$, as did a comparison between the number of infants performing a head touch in the conditions *balls* and *button*, $\chi^2(1, 38)=6.756$, $p<0.01$.

Only a small subgroup of infants immediately used their head to switch on the lamp, but by far most of the infants first used their hands (see Table 1). A Fisher's exact test showed that there was no significant difference in the number of infants who showed the head touch as first action between the five conditions (Fisher's exact test, $p=0.78$). The ANOVA revealed that there was no difference in the average number of hand touches per infant between the conditions (range 16.4-23.9), $F(4,90)=0.890$, $p=0.47$ (see Table 1), while a t-test over all infants showed that the average number of 19.3 hand touches per infant clearly outperformed the average number of 2.1 head touches per infant, $t(94)=10.631$, $p<0.001$. We additionally examined the extent to which infants in the *hands up* condition showed an attempt to lift his or her arms in the air when acting on the lamp; no infant tried to lift his arms.

| | hands free | hands occupied | button | hands up | balls |
|----------|------------|----------------|------------|------------|------------|
| HT-first | 2 (11%) | 2 (11%) | 1 (5%) | 3 (16%) | 4 (21%) |
| hands | 18.6 (2.6) | 17.1 (2.7) | 23.9 (4.7) | 20.3 (2.9) | 16.4 (2.6) |

Table 1. Number of infants in each condition performing a head touch before using their hands to switch on the light (HT-first) and average number of hand actions to switch on the light in each condition (hands). The number of infants and hand actions is given, percentages for the numbers of head touches and standard errors for the hand actions are given in brackets.

4. Discussion

The aim of this study was to investigate the role of two proposed mechanisms of imitation in infancy: motor resonance and teleological reasoning. We employed five conditions using the classical head touch imitation task (Gergely et al., 2002) and examined how often infants imitated a novel action that was demonstrated to them (i.e., switching on a lamp using the head). We manipulated the extent to which the observed actions could be matched onto the infants' own motor repertoire as well as whether the model's head touch appeared to be efficient. The results provided evidence that motor resonance, the matching of another's actions onto one's own behavioral repertoire, is an important mechanism of imitation in infancy. In contrast, no support was found for the role of a rational evaluation of the others' actions for imitative behavior in infancy.

In the condition *button* the blanket around the model's shoulders was held by a button so her hands were free. According to the rational imitation approach, infants should interpret her head action as being performed deliberately and hence many infants should imitate the head touch. This prediction was not confirmed, which casts doubt on the claim that the rational estimation of another person's actions plays an important role in imitation in infancy (e.g., Gergely et al., 2002). However, as the model performed the head action in a way the infants could hardly match onto their own motor repertoire, few infants were expected to imitate the head touch according to the motor resonance approach. Our results are in line with this prediction.

In the condition *hands up*, the model held her hands up in the air while performing the head touch. Following the rational approach, it was expected that many infants would imitate the head action because the model voluntarily used her head to turn on the lamp as her hands were free. However, holding her arms in the air reduced the infants' possibility to match the model's head action onto their own action repertoire. Critically, the number of infants who imitated the head touch was small as predicted by the motor resonance account.

Furthermore, it should be noted that we did not observe a single infant trying to lift his or her own arms in the air. This observation rules out the possibility that infants perceived this particular aspect of the action as more relevant than the head touch and tried to copy this action at the expense of the head touch action. This finding is in line with our hypothesis as the head action – and not the position of the hand – was associated with the light effect.

Therefore, when attempting to achieve the light effect, the corresponding head action gets activated (cf. Hommel et al., 2001; Verschoor, Weidema, Biro, & Hommel, 2010). The way the model performs the action (e.g., hands on the table) determines only how easily the head action can be mapped onto the infants' motor repertoire and thus how easily an action-effect association between head touch and light effect can be built in the modeling phase.

In the third new condition, *balls*, the model's hands were functionally occupied so that – following the teleological reasoning approach – only a few infants would be expected to imitate the head action. Since the model's head action was comparable to her head action in the *hands free* condition, the motor resonance account predicts that a high number of infants should show the head touch in this condition. The results were in accord with the predictions derived from the motor resonance account and therefore provide further evidence for the notion that an important mechanism subserving infants' imitation is the matching of observed actions onto their own action repertoire (e.g., Hauf & Prinz, 2005; Meltzoff, 2007).

Recent evidence from behavioral and imaging studies supports our notion that motor resonance is dependent on action experience and action capabilities (e.g., Calvo-Merino, Glaser, Grèzes, Passingham, & Haggard, 2005; Eskenazi, Grosjean, Humphreys, & Knoblich, 2009; Grosjean, Shiffrar, & Knoblich, 2007; Kilner, Paulignan, & Blakemore, 2003) and influences the way children (Lepage & Theoret, 2006) and infants perceive others' actions (van Elk et al., 2008). Our results are in accord with these findings as well as with the well-studied effects of automatic behavior matching found in healthy adults (the so-called chameleon effect; Chartrand & Bargh, 1999; cf. Bargh & Chartrand, 1999). Altogether, we suggest that automatic motor resonance plays a crucial role in imitation in infancy as it enables infants to relate an action within their own motor repertoire to an action effect. When given the possibility to retrieve this effect themselves, the corresponding action is automatically activated (Hommel et al., 2001; Wohlschläger et al., 2003).

Our finding that infants nearly always turn on the lamp but imitate the means only selectively provides further support for the notion that their imitation is goal-directed (Bekkering et al., 2000; Wohlschläger et al., 2003). According to the ideomotor principle, an intended action goal directly elicits the motor program, which is most strongly associated with it. This notion can explain why all infants, even those who performed the head action, also used their hands to turn on the light as using the hands is the default mode for this kind of action (e.g., pressing a button to get an effect). In the *hands free* and the *balls* condition,

however, there was a stronger match between the action of the model and the infants' own motor repertoire, which enabled the infants to build a new action-effect-association when they were observing the model as she performed the head actions. This motor program was subsequently also activated when infants were trying to attain the desired effect themselves, competed with the activation of the hands' motor program and, ultimately, led to the more frequent occurrence of head touches in this condition. This view supports the idea of a dynamic competition in time between several possible effectors to perform an action (see also Erlhagen & Schöner, 2002; Simmering & Spencer, 2008; Thelen & Smith, 1994). It can explain why even infants who had already turned on the lamp with their hands subsequently switched means and used their head. In contrast, this behavior is hard to reconcile within a rational approach to imitation in infancy. Specifically, infants should not consider it efficient to turn on the lamp with the head when they had already learned that the light effect could be obtained with an easier hand action.

It should be noted that our findings replicate the original study by Gergely and colleagues (2002), although in our study, in contrast to Gergely et al. (2002), the model left the experimental booth after having modeled the action. Furthermore, the communicative cues given by the model did not differ across our five conditions. Nevertheless, infants imitated the head touch to a different extent in the five conditions. These findings support the notion that infants' selective imitation of the head touch cannot solely be explained by the presence of the model or particular ostensive cues in pedagogical situations (e.g., Csibra & Gergely, 2006; Király, 2009) but supports the notion that motor resonance plays a crucial role in the head touch task.

However, a number of other studies have presented evidence for rational imitation in infants employing different tasks. For instance, Schwier, van Maanen, Carpenter, and Tomasello (2006) presented 12-month-old infants with an experimenter who played with a toy dog showing how the toy dog entered a toy house through the chimney instead of through the door. In one condition, the door was open (*door open*), whereas in a second condition, the door was closed (*door closed*). When infants subsequently were handed the toy dog and toy house with an open door to play with, more infants put the dog into the house through the chimney in the *door open* than the *door closed* condition. This finding was interpreted as evidence for rational imitation in infancy. However, one has to be careful when comparing actions which are closely connected to cultural norms (e.g., entering a house through a door instead of through the chimney) to actions derived from the application of an efficiency

principle (e.g., turning on a lamp with the hands or the head), as cultural norms of doing things in a particular way are not necessarily based on criteria of efficiency (cf. Keesing & Strathern, 1998). More importantly, however, it should be noted that the toy dog made two “forward motions with its nose practically touching the door” (Schwier et al., 2006, p. 306) before entering the house via the chimney. The infants in the *door closed* condition might have perceived the toy dog’s movements as trying but failing to enter the house through the door. Thus when infants reproduced the whole action with successful goal attainment in the subsequent imitation phase (cf. Meltzoff, 1995), their behavior could be interpreted as helping the dog to enter the house through the door, which had previously been closed (cf. Warneken & Tomasello, 2006). This was not the case in the *door open* condition where no physical obstacle was presented so that infants did not observe any failure in getting the dog into the house through the door but only the entering of the house via the chimney. Taken together, we suggest that infants’ behavior in Schwier and colleagues’ (2006) study might not result from an evaluation of the actions’ efficiency, but rather from their ability to recognize and imitate the goals underlying failed actions (cf. Meltzoff, 1995).

Our study has implications for the theoretical question about which mechanisms subserve infants’ imitation and understanding of other people’s actions (e.g., Heyes, 2001; Jones, 2007; Paulus, in press-b). In contrast to earlier explanations of this phenomenon, the present study provides evidence that motor resonance is an important mechanism of imitation in infancy. Our findings did not indicate that infants rationally assess the efficiency of an observed action in the head touch paradigm by taking into account the situational constraints, as adults probably do (Brass, Schmitt, Spengler, & Gergely, 2007; de Lange, Spronk, Willems, Toni, & Bekkering, 2008). Our findings thus point out some limits of the teleological approach and suggest that the ability to think rationally about others’ actions might not yet be fully functional in early infancy, but might emerge and gain importance later during development (see also Kuhn, 2001, 2005; Paulus et al., in press-a). Our research, however, leaves open the question whether and to what extent infants’ imitative behavior might also be susceptible to other mechanisms like social and ostensive cues (cf. Csibra & Gergely, 2006) or infants’ developing understanding about causal relations and their functional object knowledge (cf. Brugger, Lariviere, Mumme, & Bushnell, 2007). Further research is needed to closely examine the scope and limits of each of the proposed mechanisms.

Chapter 6: IMITATION IN INFANCY: RATIONAL OR MOTOR RESONANCE?

In sum, our findings shed light on the “complete mystery” (Bates, 1979, p. 332; cf. Jones, 2007) of the information-processing mechanisms behind infants’ imitation and provide evidence that motor resonance is an important, automatic mechanism subserving imitation in infancy (cf. Bargh & Chartrand, 1999). The study reveals imitation as a fascinating mechanism developed possibly as a secondary effect of evolution (Wilson & Knoblich, 2005): before infants realize that they are learning through imitation they are already doing so.

Chapter 7

The role of motor resonance in 14-month-old infants' imitation



Based on:

Paulus, M., Hunnius, S., & Bekkering, H. (submitted). *The role of motor resonance in 14-month-old infants' imitation*. Manuscript submitted for publication.

Abstract

Recently, researchers have been debating whether infants' imitation is based on sensorimotor processes (e.g., motor resonance) only or whether inferential processes like teleological reasoning (i.e., reasoning about the efficiency of others' actions) also affect infants' imitation. The present contribution directly investigates these different theoretical notions employing the seminal and widely used head touch paradigm (Gergely, Bekkering, & Kiraly, 2002). In four conditions, the observed action induced more or less motor resonance depending on the way the action was modeled, and was either efficient or not. The results suggest that 14-month-old infants do not imitate novel actions according to their efficiency, but that motor resonance plays an important role in infants' imitation.

1. Introduction

Although infants' imitation has been a topic of research within the field of developmental psychology for more than a century (e.g., Baldwin, 1906; Barresi & Moore, 1996; Piaget, 1962; Jones, 2007), the mechanisms subserving imitation in infancy are still a topic of vivid discussion (e.g., Elsner, 2007; Gergely & Csibra, 2003; Jones, 2009; Meltzoff & Moore, 1989; Paulus, Hunnius, Vissers, & Bekkering, in press-c). The teleological stance theory postulates that humans normatively evaluate actions they observe by applying the *principle of rational action* (Gergely & Csibra, 2003). Employing this principle, they expect agents to act in a way, which they infer to be most efficient for achieving their aims. Following these theoretical considerations, it has been suggested that infants (and even animals) imitate actions 'rationally', depending on the efficiency of the demonstrated action (e.g., Buttelmann, Carpenter, Call, & Tomasello, 2007; Gergely, Bekkering, & Király, 2002; Range, Viranyi, & Huber, 2007; Schwier, van Maanen, Carpenter, & Tomasello, 2006; Zmyj, Daum, & Aschersleben, 2009).

In the seminal study by Gergely and colleagues (2002), 14-month-old infants observed an adult who was sitting at a table with a black box in front of her on which a lamp was mounted. She leant forward and touched the lamp with her forehead, which caused a light effect. In one condition, the adult had a blanket wrapped around her shoulders, which she held up with her hands (*Hands occupied*) while she was performing the head touch. In a second condition, her hands were free as the blanket was hanging loosely around her shoulders (*Hands free*). More infants in the *Hands free* condition imitated the head touch than in the *Hands occupied* condition. The authors suggested that in the *Hands occupied* condition infants thought that the model had to use her head as her hands were occupied. In the *Hands free* condition, however, the model appeared to use her head deliberately and infants were thus more likely to reproduce the head touch.

Recently, however, we have presented evidence that infants' apparently "rational" imitation behavior in the head touch paradigm might be caused by another, more low-level mechanism (Paulus et al., in press-c). In the *Hands free* condition, the model supported herself with her hands on the table when performing the head touch, while in the *Hands occupied* condition she bent over with her arms crossed in front of her chest. Importantly, when imitating the head touch, infants always also put their hands on the table next to the

lamp to maintain a stable position. The action modeled in the *Hands free* condition thus resembled more closely the action as the infants performed it.

Findings have shown that a person's own action capabilities and action experiences influence the way he or she perceives the actions of others (e.g., Hauf, Aschersleben, & Prinz, 2007; Meltzoff, 2007; Sommerville & Woodward, 2005; van Elk, van Schie, Hunnius, Vesper, & Bekkering, 2008). In particular, it has been found that the observation of an action that is part of one's own motor repertoire leads to higher activation in the motor system (i.e. motor resonance) than the observation of an action that is not within one's motor repertoire (e.g., van Elk et al., 2008; see also Calvo-Merino, Glaser, Grèzes, Passingham, & Haggard, 2005). As the head action modeled in the *Hands free* condition was more similar to how the infants would perform the action themselves, it is likely that this action induced more motor resonance in the observing infant than the action which was demonstrated in the *Hands occupied* condition.

To test the hypothesis we manipulated the extent to which the observed actions could be matched onto the infants' own motor repertoire in addition to whether the observed behavior appeared to be efficient (Paulus et al., in press-c). The results suggested that motor resonance plays a central role in infants' imitation, whereas no support was found for a rational evaluation of the others' actions being a determinant of imitative behavior in infancy.

However, although one might acknowledge that motor resonance is an important mechanism subserving imitation in infancy, this does not exclude the possibility that infants' imitation is also affected by inferential processes like teleological reasoning (G. Gergely, personal communication). In other words, motor resonance might be a necessary prerequisite for imitation, but infants might – on top of that – still take the efficiency of the observed action into account.

To examine this hypothesis, we added another factor to the original design of Gergely and colleagues (2002). By changing the position of the lamp, we eliminated the differences in motor resonance between the original *Hands free* and *Hands occupied* conditions. More concretely speaking, we attached the lamp to a rack on which it could be adjusted to be at the height of the adult model's as well as the infant's head. Accordingly, infants could perform a head touch easily by leaning forward without the need to support themselves with their hands on the table. So, when the model demonstrated the head touch with her hands either free or

occupied, both actions were part of the infants' motor repertoire and were likely to lead to the same strength of motor resonance in the observing infant.

The design of the study consisted of two factors. The first factor *Lamp* described the position of the lamp (*Lamp Table*, *Lamp High*) and the second factor *Hands* the situational constraints imposed on the hands (*Hands free*, *Hands occupied*). According to the teleological stance theory we would expect that infants' imitation should be affected by the action's efficiency independent of the position of the lamp. Consequently, a main effect of *Hands* would be expected, that is imitation performance should be higher if the actor modeled the action in an inefficient manner independent of the position of the lamp. However, if motor resonance is a main factor contributing to infants' imitation performance, we expected an interaction effect between the factors *Lamp* and *Hands*, indicating that no difference between *Hands Free* and *Hands occupied* should be found in the *Lamp High* condition compared to the original *Lamp Table* situation in which a difference between *Hands Free* and *Hands occupied* should be found.

2. Method

2.1 Participants

The final sample included 71 14-month-old infants (M = 14 months, 12 days; range 13;15 – 14;31; 32 boys). The data of 38 infants in the conditions *Lamp Table - Hands free (LT-HF)* and *Lamp Table - Hands occupied (LT-HO)* were taken from the study by Paulus et al. (in press-c). Thirty-three infants were recruited to participate. The final sample included 19 infants in the *LT-HF* condition, 19 infants in the *LT-HO* condition, 17 infants in the *Lamp High – Hands Free (LH-HF)* – condition, 16 infants in the *Lamp High – Hands occupied (LH-HO)* condition. An additional 9 infants did not complete the experiment due to inattentiveness or fussiness, interference by the parent, or a procedural or technical error. The participants were healthy, full-term infants without any pre- or perinatal complications and were recruited from local birth records. The infants' parents gave informed consent for participation of their child in the study, and all participants received a book or monetary compensation for their visit.

2.2 Materials and Setting

The light box in the lamp table conditions *LT-HF* and *LT-HO* consisted of a lamp (diameter 13 cm) which was mounted onto a black box (27 x 19 x 5.5 cm). The box was positioned on a table and was filled with lead so that the infants were unable to move it. In the *Lamp High* conditions (i.e. *LH-HF* and *LH-HO*), the lamp was attached to a rack (see Figure 1). Along this rack, the lamp could be moved vertically to adjust its height. The rack was mounted onto two rails which were extended over the edge of the table so that the rack could be slid from one side of the table to the other.

A



B

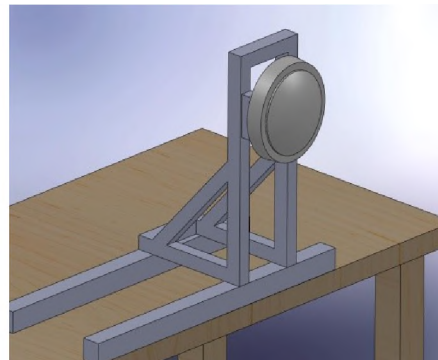


Figure 1. Figure A shows the lamp with the light box used in the *Lamp table* condition. Figure B shows a schematic drawing of the lamp on the rack used in the *Lamp high* condition.

In the conditions *LT-HF* and *LT-HO*, experimenter, parent and infant were sitting at a table, which had a rectangular section cut out of one side to allow the child comfortable access to the lamp. In the conditions *LH-HF* and *LH-HO*, the experimenter and the parent and infant were sitting at the longer edge of a rectangular table facing each other. Cameras were used to record the infant's as well as the experimenter's behavior. The blanket used in the experiment was made of blue fleece (130 x 158 cm).

2.3 Procedure

The experiment took place in an experimental booth to minimize distraction for the child. Light was dimmed to a moderate level to make the light effect of the lamp more salient. When parent and infant were seated properly, experimenter entered the booth with the

blanket. In each of the conditions the model assured eye-contact with the child and subsequently uttered the sentence '*Brrr, I feel so cold!*' while placing the blanket around her shoulders (cf. Gergely et al., 2002). The rest of the procedure during the modeling phase was different for each of the conditions.

Lamp Table conditions: In the two *Lamp Table* conditions, the lamp was placed on the table. In the *LT-HF* condition, the experimenter's hands were free. She placed the blanket around her shoulders and made sure that the infant noticed that her hands were free by rubbing her hands and moving her chair a few centimeters. Then she sat down and put her hands next to the lamp. She called the infant's name and said '*Look what I am going to do!*' The model then turned on the lamp using her forehead and returned to the initial position. The action was modeled four times. Between the head touches, the experimenter used the words '*Yes!*', '*Look!*' or called the infant's name in order to keep the infant focused. Subsequently, the experimenter said to the infant '*Would you like to try as well?*', pushed the lamp across the table in front of the infant, and left the experimental booth. The child was given 60 seconds to explore the lamp. The two conditions differed from each other as in the *LT-HO* condition the experimenter held the blanket wrapped around her shoulders, using her hands. Her hands were thus not free. The rest of the procedure followed closely the *Hands Free* condition, with the difference that the model did not support herself with her hands on the table while performing the head touch.

Lamp High conditions: The *Lamp High* conditions differed from the *Lamp Table* conditions insofar as the lamp could be adjusted to the height of the infant's head. In the condition *LH-HF*, the model showed that her hands were free, sat down on the chair and laid her hands down in her lap. For the rest, the model's behavior followed closely the condition *LT-HF*. Also the *LH-HO* condition followed closely the procedure of the condition *LT-HO*. After having performed the action sequences in the *Lamp high* conditions, the model let the blanket slip on the chair, moved the rack on the rails to the infants. The infant was given 60 seconds to act on the lamp. In all four conditions the experimenter's use of verbal and nonverbal expressions was the same.

2.4 Data analysis

The first 60 seconds after the child was given the lamp and attended to it were coded. An action was coded as a head touch when infants touched the lamp with their head. In the *Lamp table* conditions, also bending to the lamp within 10 cm of its surface was coded as a head

touch (cf. Gergely et al., 2002; Paulus et al., in press-c). To investigate to which extend infants used their hands and heads, it was registered which action infants performed first when switching on the lamp (hand or head touch). A log-linear analysis based on a logit-model (see Knoke & Burke, 1980) with the independent variables *Hand* (*Hands free*, *Hands occupied*) and *Lamp* (*Lamp Table*, *Lamp High*) and the dependent variable *Head Touch* was carried out to examine differences in the number of infants performing a head touch between the conditions. An analysis of variance (ANOVA) with the factors *Hand* (*Hands free*, *Hands occupied*) and *Lamp* (*Lamp table*, *Lamp high*) was calculated to analyze the latencies to the first head touch (for the infants who performed a head touch).

2.5 Results

In the condition *LT-HF*, 14 out of 19 infants (74%) performed a head touch, while only 5 out of 19 infants (32%) performed a head touch in the condition *LT-HO* (cf. Paulus et al., in press-c). In the condition *LH-HF*, 9 out of 16 infants (56%) performed a head touch, and 12 out of 17 infants (71%) performed a head touch in the condition *LH-HO* (see Figure 2). Hierarchical tests of logit-models revealed not only a significant main effect of the factor *Lamp* ($z=2.218, p<0.05$), but also that the interaction of both factors contributed significantly to the explanation of the data (comparison model with and without interaction effect, $z=2.309, p<0.05$). To further examine this effect, post-hoc Chi Square tests were conducted. The tests revealed that the number of infants imitating the head touch was significantly different in the *Lamp Table* conditions, *LT-HF* and *LT-HO*, $\chi^2(1, 38)=6.756, p<0.01$, but not in the *Lamp High* conditions, *LH-HF* and *LH-HO*, $\chi^2(1, 32)=0.732, p=0.39$. Furthermore, the number of infants imitating the head touch in the *Hands occupied* conditions was significantly larger in the *LH-HO* than the *LT-HO* condition, $\chi^2(1, 35)=5.461, p<0.05$, but no significant difference was found for the *Hands free* conditions, *LH-HF* and *LT-HF*, $\chi^2(1, 34)=1.172, p=0.28$.

By far most of the infants first used their hands rather than their head to switch on the lamp (85%) (see Table 1). This pattern was not different between the conditions, $\chi^2(3, 71)=3.341, p=.34$.

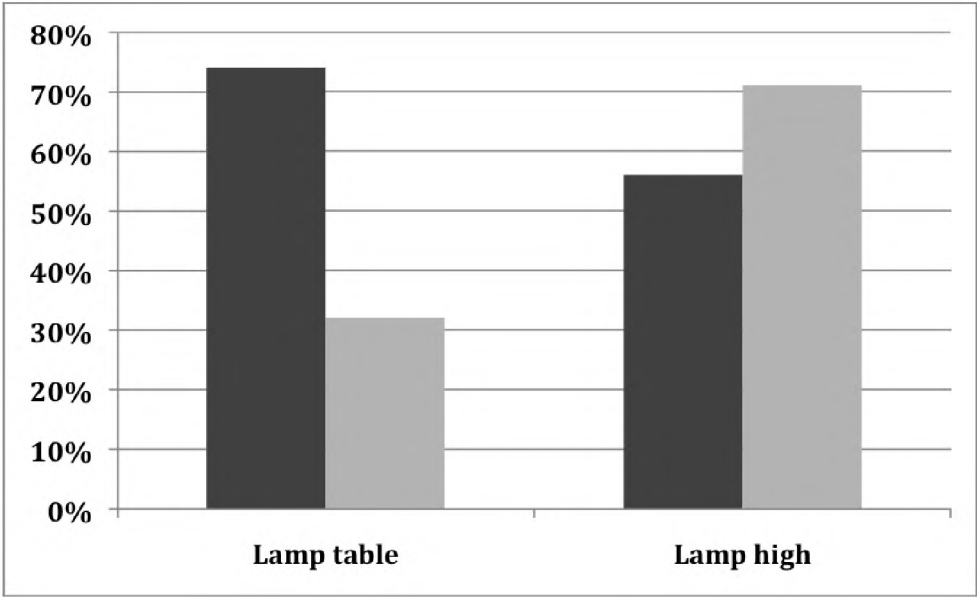


Figure 2. Percentage of infants performing a head touch in each of the experimental conditions. The two bars on the left show infants' behavior in the *Lamp table* condition, the two bars on the right in the *Lamp high* condition. The dark bars represent the *Hands free* and the light bars the *Hands occupied* conditions.

| | Lamp table | | Lamp high | |
|-------------------|------------|----------------|------------|----------------|
| | Hands free | Hands occupied | Hands free | Hands occupied |
| Head action first | 11% | 11% | 13% | 29% |

Table 1. Percentage of infants in each condition performing a head touch before using their hands to switch on the light (Head action first)

4. Discussion

The aim of this study was to examine whether teleological reasoning is an independent mechanism underlying 14-month-old infants' imitation of novel actions. More specifically, we investigated whether infants' imitation of novel head touch actions is affected by the efficiency of the demonstrated actions when the level of motor resonance they elicit is the same. Using the seminal head touch paradigm (Gergely et al., 2002), we examined how often

infants imitated the head touch in two conditions in which the model's hands were either occupied or not by holding a blanket. To eliminate the difference in elicited motor resonance between the efficient and the less efficient condition (cf. Paulus et al., in press-c), we introduced a novel factor (*Lamp High*). The results show an interaction effect of the factors *Lamp* and *Table*: when the amount of motor resonance was the same for both conditions, as it was the case when the lamp was presented at head level on a rack, no difference between the *Hands free* and the *Hands occupied* condition was observed. This suggests that 14-month-old infants did not take into consideration the situational constraints of the model and did not imitate the novel action according to their efficiency, but that motor resonance was an important factor in infants' imitation.

Importantly, the percentage of infants imitating the head touch in the *LH-HO* condition was significantly higher than in the *LT-HO* condition. This is in line with the hypothesis proposed earlier that infants' failure to imitate the head touch in the *Hands occupied* condition of the Gergely et al. (2002) study might be due to a low level of motor resonance (Paulus et al., in press-c). We suggested that the model's head action could be matched onto the infants' motor repertoire to a lesser extent in the original *Hands occupied* condition than in the *Hands free* condition, leading to less motor activation during action observation (cf. van Elk et al., 2008). In the current study, we increased the overlap between the model's and the infants' way of performing the head action by putting the lamp on a rack at the height of the infants' head, and significantly more infants imitated the head touch in the novel *Hands occupied* condition. This further corroborates the hypothesis that infants' reduced tendency to imitate the head touch in the original *Hands occupied* condition of Gergely et al. (2002) is due to a lower level of motor matching rather than their evaluation of the efficiency of the demonstrated action.

Although touching the lamp with the head was now relatively easy, 30 to 40% of the infants in our study still did not imitate the head touch at all. This is approximately the same percentage as in the *LT-HF* condition. Though the level of motor resonance is an important aspect, infants' imitation is thus affected by more than one factor. Probably it is a dynamic interaction of different factors (cf. Thelen & Smith, 1994), such as infants' previous experiences with specific learning environments (e.g., Jones & Herbert, 2008), interindividual differences in memory capacities (e.g., Kolling, Goertz, Frahsek, & Knopf, 2009), or the model's social engagement (e.g., Nielsen, Simcock, & Jenkins, 2008). Further research is needed to closely examine the interaction between these factors.

Our findings have implications for research about the mechanisms underlying imitation in infancy (e.g., Bates, 1979; Elsner, 2007; Jones, 2007; Paulus, in press-b). Gergely and colleagues (e.g., Gergely et al., 2002) suggested that infants' imitation is affected by their ability to evaluate the efficiency of observed actions. However, we argue that motor resonance might be an important mechanism subserving imitation in infancy and might probably determine infant imitation to a larger extent than rational reasoning (Paulus et al., in press-c). The current study provides additional evidence for the crucial role of motor resonance in imitative behavior but not for teleological reasoning. The results are in line with recent findings on infants' action prediction that show the limitations of infants' ability to rationally evaluate the actions of others (Paulus et al., in press-a) and suggest that this ability might emerge only later during development (e.g., Brass, Schmitt, Spengler, & Gergely, 2007; Williamson, Meltzoff, & Markman, 2009; see also Kuhn, 2005). More research is needed to investigate the development of the ability to evaluate the efficiency of others' actions.

Chapter 8

Bridging the gap between the other and me: The functional role of motor resonance and action effects in infants' imitation



Based on:

Paulus, M., Hunnius, S., Vissers, M., & Bekkering, H. (in press). Bridging the gap between the other and me: The functional role of motor resonance and action effects in infants' imitation. *Developmental Science*.

Abstract

This paper investigates a two-stage model of infants' imitative learning from observed actions and their effects. According to this model, the observation of another person's action activates the corresponding motor code in the infants' motor repertoire (i.e., leads to motor resonance). The second process guiding imitative behavior results from the observed action effects. If the modeled action is followed by a salient action effect, the representation of this effect will be associated with the activated motor code. If the infant later aims to obtain the same effect, the corresponding motor program will be activated and the model's action will therefore be imitated. Accordingly, the model assumes that for the imitation of novel actions the modeled action needs to elicit sufficient motor resonance and must be followed by a salient action effect. Using the head touch imitation paradigm, we tested these two assumptions derived from the model. To this end, we manipulated whether the actions demonstrated to the infants were or were not in the motor repertoire, i.e., elicited stronger or less strong motor resonance, and whether they were followed by salient action effects or not. The results were in line with the proposed two-stage model of infants' imitative learning and suggest that motor resonance is necessary, but not sufficient for infants' imitative learning from others' actions and their effects.

1. Introduction

The role of imitation in early development has been a topic of great interest within the field of psychology (e.g., Baldwin, 1906; Bandura, 1977; Miller & Dollard, 1941; Moore, 2006; Piaget, 1962). It has, for example, been claimed that imitation plays a central role in first language acquisition (Papoušek & Papoušek, 1989), in infants' learning about tool-use (Tomasello et al., 2005), and the facilitation of social relations (Nadel-Brulfert & Baudonniere, 1982). Taken together, it has been suggested that imitation serves cognitive as well as social functions (Uzgiris, 1981).

The mechanisms subserving imitation have remained a topic of extensive discussion over the last decades (e.g., Bates, 1979; Jones, 2007). Research has suggested that infants' imitation is affected by a relatively automatic process of perception-action matching (Paulus, Hunnius, Vissers, & Bekkering, in press-c), a natural inclination for following ostensive cues in pedagogical situations (Gergely & Csibra, 2006), the ability to read the intentions of others (Tomasello et al., 2005), or the appreciation of salient action effects (Elsner, 2007).

Findings on infants' learning about action-effect contingencies indicate that infants learn from the observation of others' actions and subsequently tend to imitate those actions that were accompanied by a salient action effect (Elsner & Aschersleben, 2003; Elsner, Hauf, & Aschersleben, 2007; Hauf & Aschersleben, 2008; Hauf, Elsner, & Aschersleben, 2004; Klein, Hauf, & Aschersleben, 2006). Hauf and Aschersleben (2008), for example, demonstrated to 7- and 9-month-old infants that pressing one of two buttons led to a salient action effect. Then, infants were allowed to play with the buttons. It could be shown that the infants tended to press first and for longer the button that led to the salient action effect. This indicates that action-effect learning is an important mechanism in infants' imitative learning from observed action-effect contingencies. Generally, the results are explained by the *Theory of Event Coding* (TEC; Hommel, Müsseler, Aschersleben, & Prinz, 2001), which suggests that actions are controlled by anticipation of their sensory effects (Elsner & Hommel, 2001). The goal to elicit a particular effect activates the corresponding motor program which has been associated with this effect and leads to the execution of the action (Hommel, 2009; Wohlschläger, Gattis, & Bekkering, 2003; for a current review see also Nattkemper, Ziessler, & Frensch, 2010).

However, the claim that infants are able to employ observed action-effect contingencies to control their own actions fails to take into account an important point. The research reported so far implicitly assumes a correspondence between the infants' own actions and the actions of another person, insofar as infants have to link their own motor system to the representation of the observed action effect. When performing a particular action, the action code and the perceptual code are related to each other via repeated co-occurrence (i.e., associative learning), so that when infants want to attain the action effect the corresponding action code (i.e., motor program) will be activated (cf. Elsner & Hommel, 2001). Applying this model to imitative learning, however, ignores the fact that there is an important gap between the other person and the infant. As the other's actions are not the infants' own actions, the question arises as to how infants are able to relate their own motor system to the representation of the corresponding action effect (i.e., build an action-effect association). In other words, it begs the question of *how* infants relate the observed actions to their own action repertoire (the "correspondence problem"; Barresi & Moore, 1996; Brass & Heyes, 2005; Heyes & Bird, 2007). The research reported in this paper addresses this question and examines one possible mechanism that enables infants to learn from the observation of others' actions and their effects.

We suggest that the mechanism of motor resonance allows infants to perceive the actions of others as corresponding to their own and to thus link actions of others to their own motor repertoire. Support for such a mechanism comes from research with adults that shows that the mere perception of another's action automatically facilitates the execution of the same motor act when the observed action is within one's own motor repertoire (Brass, Bekkering, Wohlschläger, & Prinz, 2000; Brass, Derrfuss, Matthes-von Cramon, & von Cramon, 2003; Fadiga, Fogassi, Pavesi, & Rizzolatti, 1995; Kilner, Paulignan, & Blakemore, 2003; Stürmer, Aschersleben, & Prinz, 2000; for a similar approach also see Hommel et al., 2001). It has been proposed that a human mirror neuron system might be the neural basis of the capacity to match observed actions onto one's own motor repertoire (e.g., Iacoboni et al., 1999; Rizzolatti & Craighero, 2004; Wohlschläger & Bekkering, 2002). Recent evidence from developmental studies supports the notion that infants' own action experiences and action capabilities alter the way they process the actions of others (e.g., Falck-Ytter, Gredebäck, & von Hofsten, 2006; Hauf, 2007; Hauf, Aschersleben, & Prinz, 2007; Sommerville, Woodward & Needham, 2005; van Elk, van Schie, Hunnius, Vesper, & Bekkering, 2008; cf. Hauf & Prinz, 2005). We suggest that motor resonance might be the

mechanism that serves to bridge the gap between another person's actions and the infant's own action repertoire and enables infants to form an action-effect association via observational learning. Together, whereas the literature has focused on two separate mechanisms, it is the aim of this paper to unify them into one framework. The considerations outlined in the last paragraphs give raise to a two-stage model of infants' imitative learning from the observation of others' actions and their effects (cf. Paulus et al., in press-c).

We propose that infants' observation of another person's action activates the corresponding motor code in infants' motor repertoire if the action is within their motor repertoire. If the other person's action is followed by a salient action effect, the representation of this effect (perceptual code) will be associated with the motor code (i.e., a bidirectional action-effect association will be formed; for a similar model on human action control see Elsner & Hommel, 2001). When infants later want to obtain the same effect, the corresponding motor program will be activated.

The current paper tested the two basic assumptions of this qualitative model. First, the assumption that a modeled action needs to resonate in the motor system of the infant predicts that demonstrated actions that induce little motor resonance are unlikely to be imitated, even if they are followed by a salient action effect. Second, the assumption that infants strive for salient effects predicts that an action that elicits strong motor resonance but is not followed by a salient action effect is also unlikely to be imitated. For imitative learning of novel action-effect contingencies to take place, the modeled action needs to elicit sufficient motor resonance (i.e., needs to be in the motor repertoire of the infant) and must be followed by a salient effect.

To investigate these hypotheses we built on the findings of a study by Paulus and colleagues (in press-c) in which infants observed how a model touched a lamp on a table in front of her with her head to turn on the light (cf. Gergely, Bekkering, & Kiraly, 2002). It has been found that infants always imitated the head action supporting themselves with both hands on the table, probably to maintain a stable posture while bending over⁵. Importantly, the frequency with which infants imitated the head touch was higher in conditions in which the model also put her hands on the table while performing the head touch, than in conditions

⁵ To provide quantitative support for this notion we recoded infants' behavior during the test phase of the study of Paulus et al. (in press-c). Out of 95 participants, 43 showed at least one head touch. Of these 43 infants, 100% imitated the head touch supporting themselves with both hands on the table.

in which she performed the head action in a different manner (e.g., with her arms crossed on her chest, or with her arms in the air). These previous results stressed the importance of motor resonance for imitation in infancy, as many infants imitated the novel action in conditions in which there was a greater overlap between infants' way of performing the action and the model's way of demonstrating the action.

To address the questions of whether motor resonance is necessary and sufficient for infants' imitation and thus mediates action-effect learning through observation, we investigated the interplay of motor resonance and learning from observed action-effect contingencies in the head touch task. For this purpose, we examined infants' imitative behavior in three novel conditions that we directly compared with the results of two conditions from our previous study (*Hands free* and *Button*; cf. Paulus et al., in press-c). In the original *Hands free* condition the model demonstrated the head action while supporting herself on the table with her hands. In the original *Button* condition, the model wore a blanket, which was held in place by a button. When demonstrating the head touch, she crossed her arms in front of her chest. Interestingly, more infants imitated the head touch in the *Hands free* than in the *Button* condition, which is in line with the notion that motor resonance plays a crucial role in infants' imitation (Paulus et al., in press-c). In all three novel conditions we used a modified version of the original lamp task in which a small switch had been added to the lamp, which deactivated the lamp, so that the light effect could no longer be elicited.

The new *Head Effect* condition was comparable to the *Button* condition⁶ as the model turned on a lamp with her head while she had her arms folded in front of her upper body under the blanket. In the original *Button* condition, only a small number of infants imitated the head touch, whereas all infants repeatedly turned on the lamp with their hands. We modified this condition in our novel *Head Effect* condition so that the model switched the lamp off before giving it to the child so that no effect could be elicited. As the infants normally first try to turn on the lamp with their hands (e.g., Paulus et al., in press-c), infants would experience that pressing the lamp with their hands does not lead to the effect. At the same time, they had observed during the demonstration phase that the model turned on the

⁶ We chose to modify the *Button* condition (Paulus et al., in press-c) instead of the original *Hands occupied* condition (cf. Gergely et al., 2002), as in this condition the model's hands remained free. This was important for our second new condition *Head Only* as the model needed her hands to demonstrate a hand action on the lamp.

lamp with her head. If motor resonance is not a prerequisite for infants' imitative learning we would expect that more infants – after having experienced that they cannot switch on the lamp with their hands – would imitate the head touch in the new *Head Effect* condition than in the original *Button* condition in which the lamp could also be turned on with the hands. If motor resonance, however, is a necessary prerequisite for infants' imitative learning about observed action-effect contingencies we would expect that despite their failure to switch on the lamp with their hands still only a few infants would try to switch it on with their head. Accordingly, we would expect that the number of infants performing a head touch would be smaller compared to a condition in which more motor resonance occurs, e.g. the *Hands Free* condition, and comparable to other conditions with little motor resonance, e.g. the *Button* condition.

The second new condition, *Head Only*, was comparable to the *Head Effect* condition. For this condition, however, we additionally manipulated another factor besides turning the lamp off before giving it to the child (as in the *Head Effect* condition). The model not only demonstrated that the lamp could be turned on with the head (as in the *Button* and the *Head Effect* conditions) but she also showed that pressing the lamp with the hand did not produce the light effect. As it has been argued that infants' imitative learning is influenced by the pedagogical context in which the model demonstrates the action (cf. Kiraly, 2009; Gergely & Csibra, 2006), one might argue that an explicit demonstration of action consequences (i.e., demonstrating how the effect can and cannot be obtained) should facilitate infants' learning from observed action-effect contingencies (cf. Kiraly, 2009). Accordingly, if motor resonance is not a prerequisite for infants' imitation, infants should be able to make use of the explicitly demonstrated action-effect contingency. In particular, more infants should imitate the head touch than in the *Button* and the *Head Effect* condition as it was clearly demonstrated that only the head, but not the hand action led to the desired light effect. If motor resonance, however, is a necessary prerequisite for infants' imitative learning from others' actions we expected that only a small number of infants will perform the head touch in the *Head Only* condition.

The third new condition, *No Effect*, investigated the role of salient action effects in conditions with high motor resonance. In particular, we were interested in whether infants would imitate the head touch if no light effect at all would be obtained by the model. In other words, is motor resonance sufficient to induce a high rate of imitative behavior even though no salient effect will be activated? The model took the same blanket and followed exactly the

same procedure as in the *Hands free* condition with the exception that the lamp remained deactivated during the entire experimental session. When the model demonstrated the head action, no light effect was produced. If action effects play an important role in infants' imitative learning, we would expect that only a minority of infants would perform the head touch in the *No Effect* condition. If, however, motor resonance is sufficient to induce imitative behavior, many infants should imitate the head action (for an overview of all conditions see Table 1).

| CONDITION | DEMONSTRATION | | | TEST |
|-------------|-----------------|-----------------|----------------|----------|
| | Hand Action | Head Action | Position Hands | |
| Hands free | | Head->light | Hands on table | Lamp on |
| Button | | Head->light | Hands crossed | Lamp on |
| Head Effect | | Head->light | Hands crossed | Lamp off |
| Head Only | Hand->no effect | Head->light | Hands crossed | Lamp off |
| No Effect | | Head->no effect | Hands on table | Lamp off |

Table 1. Table 1 visualizes the design of the study. The first column represents the five conditions. The second till the fourth column shows the actions during the demonstration phase. The last column shows whether the lamp was turned off during the test phase or not.

2. Method

2.1 Participants

The final sample included 96 14-month-old infants (Range 13; 15 – 14; 31; 47 boys). The data of 38 infants in the conditions *Hands free* and *Button* were taken from the study by Paulus et al. (in press-c) and were reanalyzed for our purposes. 58 infants were recruited to participate in the experiment. The final sample included 19 infants in the *Hands free* condition, the *Button* condition, the *Head Effect* condition, the *Head Only* condition, and 20 infants in the *No Effect* condition. An additional 11 infants did not complete the experiment due to inattentiveness or fussiness, interference by the parent, or a procedural error. The participants were healthy, full-term infants without any pre- or prenatal complications and were recruited from local birth records. The infants' parents gave informed consent for participation of their child in the study and were given a baby book or monetary compensation for their visit.

2.2 Materials and Setting

The light box consisted of a lamp (diameter 13 cm), which was mounted onto a black box (27 x 19 x 5.5 cm). The box was filled with lead so that the infants were unable to move it. On the front side of the box there was a toggle switch that could be used to turn off the lamp. The switch was invisible for the infant, due to its size (1 x 1 x 3 mm), its black color, and the fact that the switch was on the back side of the box (see Figure 1A for a picture of the box). The blanket used in the *Head Effect* and the *Head Only* conditions was made of blue fleece (130 x 158 cm) and had a clearly visible red button (diameter 8 cm) attached to it. A buttonhole had been made for the button. The blanket used in the *No Effect* condition resembled the other blanket, though without a button or a buttonhole.

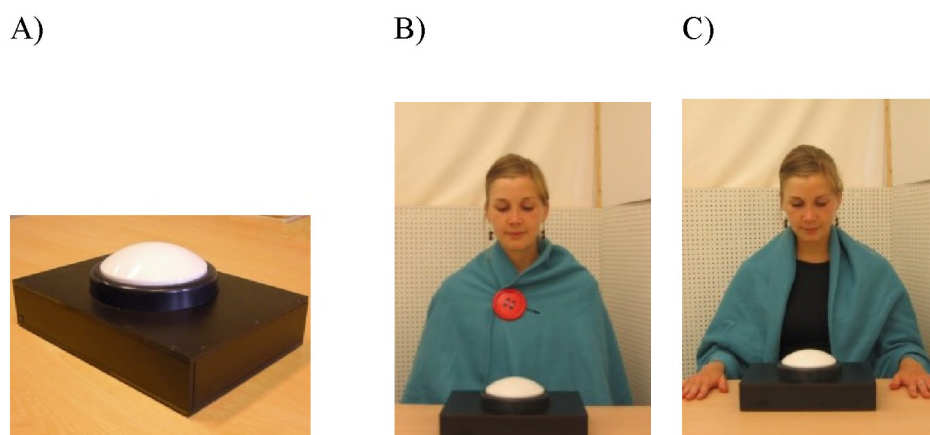


Figure 1. Figure 1A shows a picture of the lamp. Figures 1B and 1C show the model's position before performing the head touch in the different conditions (1B Button/ Head Effect/ Head Only; 1C Hands free/ No Effect).

The caregiver and the infant were sitting at a table which had a square spearing on the side at which they were seated. The infant was seated on the caregiver's lap in the spearing with his or her belly against the tabletop. Two cameras were used to record the infant's and the experimenter's behavior during the experiment.

2.3 Procedure

The procedure followed closely the procedure of Paulus et al. (in press-c). Before starting the experiment, the experimenter took time to let the infant get used to the testing room. Parents were given an instruction which contained information about the way the infant had to be positioned on the lap and the way the parent was supposed to behave during the experiment.

The experiment took place in an experimental booth to minimize distraction for the child. When the parent and the infant were seated properly, the experimenter left the experimental booth for a few moments. Light was dimmed to a moderate level in order to make the light of the light box in the *Head Effect* and the *Head Only* conditions more salient. Then the experimenter re-entered the booth with the blanket. To make everything as comparable as possible to the original conditions (see for the rationale Paulus et al., in press-c), in each of the conditions the model started with the sentence '*Brrr, I feel so cold!*' to direct the infant's attention to her behavior⁷, making sure that the infant paid attention to her

⁷ Please note that Paulus et al. (in press-c) were interested in a different question, namely if infants' imitation is rational or subserved by motor resonance. To that end, they introduced a cover story, in which the model uttered that she felt cold and subsequently placed a blanket around her shoulders. The blanket was either hold by the hands or not, so that the model's hands were free or not while

by making eye-contact. The further procedure in the modeling phase was different in each condition.

In the condition *Head Effect*, the model placed the blanket around her shoulders, which was held by a button. To make sure that the infant perceived that her hands were free, the model rubbed her hands and grasped the chair to move it a few centimeters. Then she sat down and crossed her arms under the fleece in front of her upper body (see Figure 1B). She made sure to have the infant's attention by assuring eye contact and saying '*Look what I am going to do!*' If eye contact was not established immediately, the experimenter called the infants name, followed by '*Watch this!*' to receive attention again. Then the model performed the head touch: she bent forward, turned on the lamp by pressing it with her forehead and returned to the initial upright position. The head touch was modeled four times. In between the head touches, the model assured eye contact with the infant and smiled mildly. If an infant used vocalizations during the modeling phase, the model replied with '*Yes!*' When the model noticed that the infant did not pay attention to her when she was in the upright position during the modeling phase, she would say '*Look!*' to keep the infant focused. Additionally, she called the infant's name when the infant did not pay attention anymore. After having performed the action sequence, the experimenter released the button and let the blanket slip on the chair. Then the model turned off the lamp using the small switch on the model's side of the light-box, while simultaneously asking the infant '*Would you like to try as well?*', to make sure the infant would not notice the experimenter turning off the lamp. Then she cautiously moved the lamp across the table to put it in front of the infant. This was done in a way in which the small, black switch remained on the side of the box that could not be seen by the infant. The model stood up and left the experimental booth without looking at the child and mother again. After the experimenter left, the child was given 60 seconds to act on the lamp. When the 60 seconds had passed, the experimenter reentered the booth and informed the parent about the rationale behind the experiment.

The *Head Only* condition resembled the *Head Effect* condition with the difference that the lamp had been deactivated before the experiment. After sitting down, the model first tried to turn on the lamp with her hand. To this end she pressed the top of the lamp with her right hand while looking at it. As described above, the lamp was turned off before the experiment so that no light effect was produced. After every attempt to turn on the lamp with her hand,

performing the head touch (cf. Gergely et al., 2002). Although this story was not important for our current study, we closely followed the procedure of Paulus et al. (in press) in our novel conditions, to keep our results comparable to their findings.

she moved her hand back to her body again and frowned every time she pressed the lamp. The hand action was performed four times. In between, the model assured eye contact with the infant. When she noticed that the infant did not pay attention to her, she used the words 'Yes!' or 'Look!' in order to keep the infant focused. She also called the infant's name when the infant did not pay attention anymore. After the model performed the hand action four times she ensured that there was eye contact with the infant and said '*Have another look at what I am going to do!*' While saying this, the model turned on the lamp by pressing the switch that was on her side of the lamp. This was done simultaneously to prevent the infant from noticing the lamp being switched on. After the lamp had been switched on, the experiment followed closely the procedure in the *Head Effect* condition. The *Button* condition was exactly the same as the *Head Effect* condition with the only exception that the experimenter did not turn off the lamp when giving it to the infant. The infants were able to elicit the light effect by pressing the lamp with their hands or heads.

The *Hands free* condition differed from the other conditions as the model placed the blanket without the button loosely around her shoulder and put her hands next to lamp instead of crossing them in front of her upper body (see Figure 1C). That means when performing the head touch the model was supporting her upper body part by having her hands lying next to the lamp. In this condition the lamp was not turned off when given to the infant as it was in the *Button* condition. The *No Effect* condition was almost the same as the *Hands free* condition, the only difference being that the lamp remained turned off during the whole experiment. The light effect could not be activated by either the experimenter or the infant. In all conditions, the experimenter's use of verbal and nonverbal expressions was the same. No other language was used during the experiment besides the phrases mentioned above.

2.4 Data analysis

The first 60 seconds were coded after the child was given the lamp and attended to it. A head touch was defined as a movement of the head towards the lamp, whereby the infant's head was within a distance of 10 centimeter from the lamp. We coded if infants performed at least one head touch or no head touch at all. This coding procedure is identical with previous studies (cf. Gergely et al., 2002; Paulus et al., in press-c). To investigate to which extent infants relied on their hands and heads, it was registered which action infants performed first when acting on the lamp (hand or head action) and how often they used their hands (hand touch). Chi square tests were carried out to examine differences in the number of infants

performing a head touch between the conditions (cf. Gergely et al., 2002). An analysis of variance (ANOVA) with the factor condition was calculated to analyze the frequency of hand touches. Furthermore, we compared the latencies to the first head touch between the conditions by calculating an ANOVA.

3. Results

In the condition *Hands free*, 14 out of 19 infants (74%) performed the head touch while in the condition *Button* five out of 19 infants performed the head touch (26%; cf. Paulus et al., in press-c). In the new condition *Head Effect*, six out of 19 infants performed the head touch (32%; see Figure 2). Chi Square Tests revealed that the difference between the number of infants imitating the head touch in the *Head Effect* condition and the *Hands free* condition was significant ($\chi^2(1, 38) = 6.756$; $p < 0.01$) whereas no statistical difference could be found between the number of infants imitating the head touch in the *No Effect* condition (7 out of 20 infants; 35%) and the *Button* condition ($\chi^2(1, 38) = 0.128$; $p = 0.721$), 35% and 26%, respectively. In the condition *Head Only* five out of 19 infants performed the head action (26%). The number of infants imitating the head touch in the *Head Only* condition was significantly smaller than in the *Hands free* condition ($\chi^2(1, 38) = 8.526$; $p < 0.01$), but not different from the *Button* condition ($\chi^2(1, 38) = 0$; $p = 1$). A further comparison between the condition *No Effect* and the condition *Hands free* was conducted to investigate whether the head touch was differently imitated, when it led to a salient action effect or not. A significant difference was found between the *Hands free* and the *No Effect* condition ($\chi^2(1, 38) = 5.867$; $p < 0.05$).

| | Button | Hands Free | Head Effect | Head Only | No Effect |
|---------------------|------------|------------|-------------|------------|------------|
| Latency | 22.2 (8.4) | 29.9 (4.9) | 23.2 (8.2) | 20.6 (7.5) | 24.3 (8.3) |
| Hand Touches | 23.9 (4.7) | 18.6 (2.6) | 13.7 (2.5) | 18.3 (2.3) | 18.2 (2.2) |

Table 2. Latencies to the first head touch when a head touch was performed (Latency), and average number of hand actions (Hands) in each condition. Standard errors for the hand actions and latency scores are given in brackets.

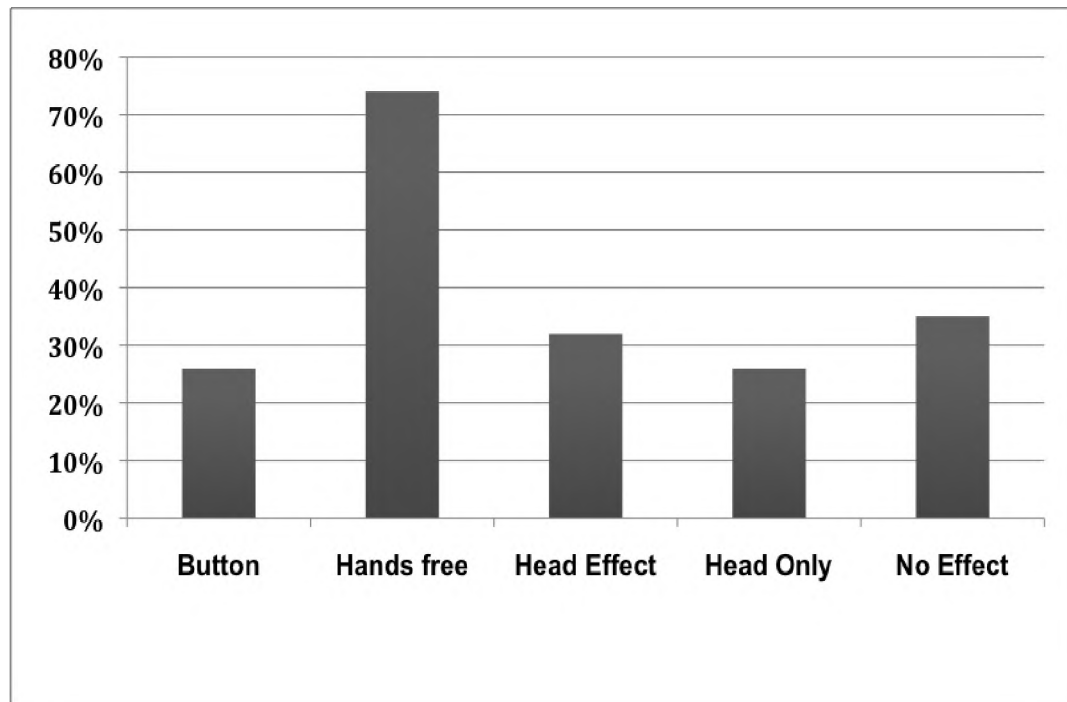


Figure 2. Percentage of infants performing a head touch in the five experimental conditions.

Only a small subgroup of infants immediately used their heads to switch on the lamp, but by far most of the infants first used their hands. A Fisher's exact test showed that there was no significant difference in the number of infants who showed the head touch as first action between the five conditions (Fisher's exact test, $p=0.21$). An ANOVA revealed that there was no difference in the average number of hand touches per infant between the conditions (range 13.7-23.9; $F(4, 91)=1.439$, $p=0.23$, see Table 2). The infants who imitated the head touch in each of the different conditions, did it with approximately the same latency (range 20.6s – 29.9s; $F(4, 32)<1$, see Table 2).

4. Discussion

The aim of this study was to test two assumptions derived from our two-stage model of infants' imitative learning of novel action-effect associations. In particular, we examined the contribution of two distinct processes in 14-month-old infants' imitative learning: the role of motor resonance and that of salient action effects. The first assumption was that a modeled action that induces little motor resonance would unlikely be imitated, even if followed by a salient action effect. The role of motor resonance was tested in the comparison between the *Button* and the *Head Effect* respectively *Head Only* conditions. The results showed that only

a few infants imitated the head touch even though it was followed by a salient effect during the modeling phase and even though infants experienced that they could not turn on the lamp with the prepotent hand action. The second assumption was that infants would strive to imitate actions that lead to salient action effects. Therefore, a modeled action that does not lead to a salient effect would be unlikely to be imitated, even though it induces sufficient motor resonance. The role of action effects was tested in the comparison between the *Hands free* and the *No Effect* conditions. The results were in line with our predictions. Together, these findings provide support for our two-stage model as they suggest that imitative behavior in infancy is subserved by the interplay of two mechanisms: motor resonance and action-effect learning.

An alternative explanation for infants' failure to make use of the observed action-effect contingencies in our *Head Only* condition is that infants could simply have assumed that the lamp was not working anymore because the model's hand touch did not lead to a light effect. However, this explanation cannot account for the findings in the *Head Effect* condition in which only successful head touches were demonstrated and nevertheless only a minor number of infants imitated it. Furthermore, no differences in the number of hand touches were found between the different conditions. That suggests that infants were equally engaged in the task in both conditions. Finally, it should be noted that the model always first demonstrated the unsuccessful hand action and subsequently performed the head action, which led to the salient action effect, making clear that there was no technical problem with the lamp.

It should be noted that in some of the conditions the infants were not able to turn on the lamp with their head, as the lamp was turned off in the test phase (see Table 1). However, as we were interested in the number of infants who performed at least one head touch or no head touch at all, it was irrelevant whether infants eventually perceived a light effect once they performed the head touch or not. Differences between conditions could thus not be explained by the different consequences of performing a head touch, but rather by the different demonstrations in the demonstration phase.

Recent empirical findings support our notion that motor resonance affects infants' perception of other people's actions. It has, for example, been suggested that infants' perception of others' actions as object-directed (Sommerville et al., 2005; Sommerville & Woodward, 2005) and their ability to imitate an action (Paulus et al., in press-c) depend on

their own capacity to perform these actions themselves. Furthermore, electrophysiological evidence has been provided for motor activation in infants and children, when they observe actions that are in their motor repertoire (Lepage & Theoret, 2006; van Elk et al., 2008). Our findings extend this knowledge insofar as they clarify the exact role of motor resonance in infants' imitation. They show that motor resonance forms a necessary, though not sufficient prerequisite for infants' imitative learning from other people's actions and their effects.

Although research has provided evidence of several factors that influence imitation in infancy, suggesting that infants' imitation may be affected and subserved by various mechanisms (Jones, 2009), the question of *how* infants are able to learn from observed actions and their effects has widely been neglected (cf. Brass & Heyes, 2005). Implicitly, it has been assumed that infants can bridge the gap between themselves and others by matching the actions of others onto their own motor repertoire (Elsner & Aschersleben, 2003; Hauf et al., 2004; Hauf & Aschersleben, 2008). We provide evidence that the mechanism that supplies this essential basis for imitation in infancy might indeed be motor resonance.

Furthermore, our results provide evidence that motor resonance is not only an optional factor, but is a necessary mechanism in infants' imitative learning from observed action-effect contingencies. Paulus and colleagues (in press-c) have shown that by slightly changing the way of demonstrating the head touch (*Hands free* vs. *Button* condition) and thus the level of induced motor resonance the number of infants who are imitating the head action can be significantly reduced. We manipulated the *Button* condition in our novel *Head Effect* and *Head Only* conditions by giving the infants additional cues that only a head touch, but not a hand action can elicit the salient effect. Even though it has been shown that infants are able to profit from such explicit demonstrations in pedagogical situations (Kiraly, 2009; cf. Csibra & Gergely, 2009), infants largely failed to perform the head touch when subsequently having the opportunity to act on the lamp. Importantly, in all three novel conditions (*Head Effect*, *Head Only*, *No Effect*) the number of infants who imitated the head touch was about the same and was significantly smaller compared to the *Hands free* condition. We therefore propose that motor resonance is an obligatory mechanism involved in infants' imitative learning from other people's actions and their effects. Only when infants are able to map the perceived actions of others onto their own motor repertoire (see also Hommel et al., 2001), can they acquire novel action-effect associations through observation.

Our results also provide evidence for the role of action effects in infants' and children's imitation in general (Elsner et al., 2004; Hauf & Aschersleben, 2008; see also Bekkering, Wohlschläger, & Gattis, 2000; Gleissner, Meltzoff, & Bekkering, 2000; Wohlschläger et al., 2003). Note that the action performed by the model in the *No Effect* condition was exactly the same as in the *Hands free* condition, but that the conditions differed insofar, as only in the *Hands free* condition the action was followed by a salient effect. The withdrawal of the salient action effect drastically reduced how many infants imitated the head touch. This result is in line with findings that emphasize the role of action effects in infants' imitation (for a review see Elsner, 2007).

In all conditions, infants also displayed frequent hand actions in addition to the head touches. There might be two reasons for the occurrence of these hand actions: On the one hand, infants' hand actions could be exploratory mechanisms in the service of manually examining the novel object. Research on infants' actions with novel objects has shown that slapping, hitting, and tipping the surfaces of heavy objects belong to the repertoire of exploratory actions in infancy (Paulus & Hauf, in press). On the other hand, one could apply the ideomotor principle also to the occurrences of hand actions in the head touch imitation task (Paulus et al., in press-c). According to the ideomotor principle, an intended goal directly elicits the motor program that is most strongly associated with it (Wohlschläger et al., 2003). It is reasonable to assume that using the hands to switch on the light is the default mode for this kind of action (e.g., pressing a button to get an effect). We suggest that besides the already established link with the hand action, infants in the *Hands free* condition perceived a stronger match between the head action of the model and their own motor repertoire, which enabled them to build a new action-effect association in the demonstration phase. As this motor program became thus linked with the light effect, it was subsequently also activated when the infants were trying to obtain the desired effect. According to this model, it competed with the activation of the hands' motor program and, eventually, led to the more frequent occurrence of head touches in this condition (for similar approaches, stressing a dynamic competition between effectors, see also Erlhagen & Schöner, 2002; Thelen & Smith, 1994).

Although our results provide evidence for the role of motor resonance and action effects in infants' imitation, it is striking that even in the *Hands free* condition only 74% of the infants imitated the head touch. This suggests that other factors have to be considered, such as infants' previous experiences with certain learning environments (e.g., Jones &

Herbert, 2008), momentary motivational states like tiredness, or memory capacity of infants (e.g., Kolling, Goertz, Frahsek, & Knopf, 2009).

On the other hand, 26% or more of the infants imitated the head touch in the four conditions in which either motor resonance was reduced or the light effect was absent. One could interpret this finding as evidence that motor resonance and salient action effects are important, though not necessary mechanisms. However, this proportion might represent infants' basic inclination to act on the lamp with their head, maybe as a part of infants' explanatory actions (e.g., mouthing an object; Paulus & Hauf, in press; see also Jones, 2009). This interpretation is supported by recent findings of Zmyj and colleagues (2009) who examined 1-year-old infants' behavior in a baseline condition of the head touch imitation task. In this condition, infants were presented with the light box without having seen any demonstration. Interestingly, approximately 20% of the infants performed a head touch on the lamp. A comparable number of infants performed the head touch when either motor resonance was reduced or the light effect was absent. This finding is in line with our hypothesis that infants' imitation relies on the interplay of motor resonance and salient action effects.

4.1 A two-stage model of imitation in infancy

Altogether, our study provides empirical support for our two-stage model of infants' ability to learn and imitate observed action-effect contingencies (for a comparable model concerning action control see Elsner & Hommel, 2001). We suggest that first a mechanism of motor resonance is necessary to overcome the correspondence problem (cf. Brass & Heyes, 2005). In this first step, the perception of an action that is part of the infants' motor repertoire leads to the activation of the same action (e.g., van Elk et al., 2008).

Second, if mapping of others' actions onto the infants' motor repertoire is possible, the activated motor program can be associated with the cognitive representation of a concurrently perceived action effect. In other words, if a demonstrated action is accompanied by a salient action effect, the activation of the infants' own motor response is linked to the representation of the action effect so that subsequently the corresponding motor program gets activated, when infants aim to retrieve this effect themselves (cf. Hommel et al., 2001).

Although it was not the focus of our research, the previous statements raise the question of how motor resonance develops during early infancy. On the one hand, it can be argued that

motor resonance rests upon infants' ability to represent their own as well as others' bodies in a common, intermodal representational format which they might possess from very early on (Meltzoff & Moore, 1989) or a common coding of perception and action in a commensurable format (Hommel et al., 2001; Prinz, 1997). This would enable infants to match observed movements onto their kinesthetic representation of own actions and allow imitation of even very young infants (e.g., Meltzoff & Moore, 1977). On the other hand, it has been suggested that motor resonance is based on Hebbian learning (Ray & Heyes, in press). More specifically, it has been proposed that by observing the consequences of their own actions (e.g., moving an arm) the representation of these action effects (e.g., the visual perception of the moving arm) will be linked to the motor code. When the same action (e.g., an arm movement) is subsequently performed by another person and perceived by the observer, the activation of the perceptual code will automatically activate the associated motor code (Catmur, Walsh, & Heyes, 2007; Del Giudice, Manera, & Keysers, 2009; see also Barresi & Moore, 2008). Further research is necessary to investigate these possibilities. However, whatever the precise developmental origin of motor resonance may be, our results suggest that it plays a fundamental role in infants' ability to imitate and to learn from the actions of others.

Chapter 9

Action-effect binding by observational learning



Based on:

Paulus, M., van Dam, W., Hunnius, S., Lindemann, O. & Bekkering, H. (submitted). *Action-effect binding by observational learning*. Manuscript submitted for publication.

Abstract

The acquisition of bidirectional action-effect associations plays a central role in the ability to control actions. Humans learn about actions not only through active experience, but also through observing the actions of others. This study examined whether action-effect associations can be acquired by observational learning. To this end, participants observed how a model repeatedly pressed two buttons during an observation phase. Each of the button presses led to a specific tone. When in a subsequent test phase the tones served as stimuli, to which the participants had to respond with button presses, they performed faster when the stimulus-response mapping in the test phase was compatible with the action-effect mapping of the observation phase. A second experiment controlled for the possibility that the results might be due to the association of spatial perceptual features (i.e., left or right) with the particular tone, and shows that the observation of a real action is necessary to acquire novel action-effect associations. Altogether, the study provides evidence for the claim that bidirectional action-effect associations can be acquired by observational learning. We discuss the possibility that the acquisition of action-effect associations through observation is an important cognitive mechanism subserving the human ability for social learning.

1. Introduction

An influential account on action control has proposed that actions are controlled through bidirectional action-effect associations (Elsner & Hommel, 2001; Hommel, Müsseler, Aschersleben, & Prinz, 2001; Kühn, Elsner, Prinz, & Brass, 2009; Kunde, Hoffmann, & Zellmann, 2002). According to this ideomotor approach, actions are represented in terms of their sensory consequences and action knowledge is acquired through the repeated experience of co-occurrences of actions and their effects (cf. Hommel, 1997). The cognitive representations of intentional actions are therefore characterized by the associations of motor codes with the representations of their sensory consequences (i.e., sensory codes). As the intention to elicit a particular sensory effect is assumed to activate directly the motor program associated with this effect, acquired action-effect associations can be later used for the control of actions (Hommel, 2009).

Evidence for this notion has, for example, been provided by Elsner and Hommel (2001). Participants had to press buttons as a response to a visual stimulus and experienced the co-occurrence of their button presses with specific tones. Importantly, these tones were irrelevant to the participants' task. In a subsequent test phase, participants were presented with both tones again. This time they were asked to press the buttons in response to the tones, which had previously followed the button presses. It could be shown that participants' responses were facilitated when the preceding tone had previously been the consequence of this action (i.e., were perceived as effect of the action), indicating that the perception of the tone activated the corresponding motor program.

However, action knowledge is not only acquired through active action experiences, but also through the observation of other people's actions (e.g., Blandin, Lhuisset, & Proteau, 1999; Cross, Kraemer, de C. Hamilton, Kelley, & Grafton, 2009; see also Bandura, 1977), suggesting that we use observed information about other people's actions and their effects to control our own actions. The claim that all actions are cognitively represented and selected in terms of their effects (e.g., Hommel et al., 2001), and the findings that people acquire action knowledge not only through active action experiences but also through the observation of other people's actions, leads thus to the hypothesis that bidirectional action-effect associations can also be acquired by observational learning. Importantly, to employ observed action-effect contingencies for our own action control, we need to relate our own motor codes to the cognitive representation of the observed effect of another person's action. Previous

research has shown that the mere perception of another's action facilitates the execution of the same action in the observer's motor repertoire (i.e., motor resonance; Brass, Bekkering, Wohlschläger, & Prinz, 2000; Fadiga, Fogassi, Pavesi, & Rizzolatti, 1995). Considering these findings of automatic motor activation during action observation, we propose that novel action-effect associations can also be acquired through observation. In particular, we suggest that during the observation of another person's actions and the effects of these actions, sensory codes (i.e., the representation of the observed effect) and motor codes (i.e., the representation of the observed movement) can become associated and a new bidirectional action-effect association can thus be acquired.

In the present study we integrated the ideas of observational learning and ideomotor action control. We examined whether the observation of another person's actions and their effects results in an incidental learning of action-effect associations that modulates subsequent action execution as it has been shown for the acquisition of such associations through own action experiences (Elsner & Hommel, 2001). In an action observation phase, the participants observed another actor pressing two buttons that triggered two different auditory effects. In a subsequent test phase, the same tones were presented as stimuli to which the participants had to react as quickly as possible with button presses. If responses are faster in a condition in which the stimulus-response mapping in the test phase is compatible with the action-effect mapping in the observation phase as compared to a condition with the reversed mapping, this would provide evidence for the notion that participants are able to acquire action-effect associations via social learning.

2. Experiment 1

2.1 Method

2.1.1 Participants

A total of 24 students of the Radboud University Nijmegen (18 – 31 years; 6 male) participated in the experiment in return for 8 euros or course credits.

2.1.2 Set-up and stimuli

A LED device was used to present the visual stimuli in the observation phase to the participant and the experimenter. The device contained two displays (77 x 18mm), one facing

the participant and the other facing the experimenter (see Figure 1). The participant was not able to see the display of the experimenter. Both participants were seated at a viewing distance of approximately 75 cm. Visual stimuli consisted of left- and right-pointing arrowheads. The device was positioned in the middle of a table and oriented along the table's longer edge. At the left and right hand side of the device were two buffer buttons (diameter 5 cm; 3.5 cm high). Initially, the buttons were positioned close to the experimenter's side of the table. One of the buttons was red, the other one black. Auditory stimuli were 400-Hz and 800-Hz tones, presented for 200 ms simultaneously through two speakers to the left and right side of the participant. The experiment was controlled by Presentation (Neurobehavioral Systems, USA).

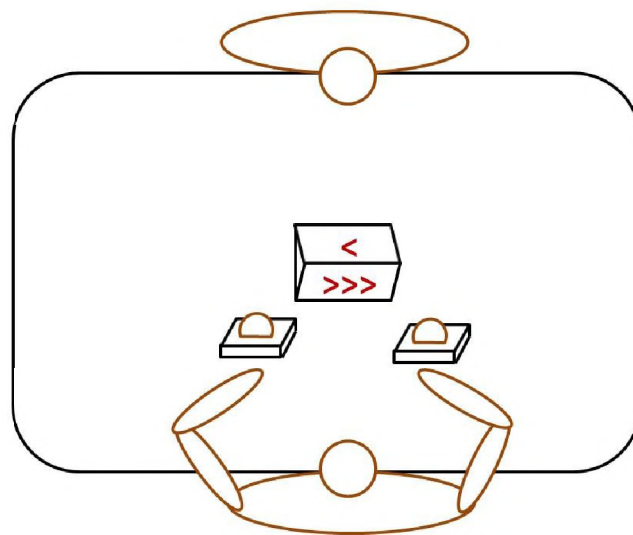


Figure 1. Schematic overview of the experimental setup showing actor (bottom) and observer (top).

2.1.3 Procedure and Design

Observation phase. Participants were introduced to the experimenter and seated opposite to him. On the displays of the LED device, arrowheads were presented at the beginning of each trial. The experimenter performed left and right button press responses as instructed via the arrowheads on his display. Each button triggered one of two different sound effects (i.e., low or high pitch). In about 20 % of the trials (randomly distributed) the arrowheads on the two sides of the LED device pointed in two different directions.

Participants were informed that the tones were irrelevant to the task (cf. Elsner & Hommel, 2001). They were instructed to closely observe the experimenter's actions and

count the incorrect responses. To be precise, we asked participants to count how often the experimenter performed a button-press on the side, which had not been indicated by the arrowhead on the participants' display. Importantly, these "incorrect responses" did not affect the action-effect mapping between action and tone, as the button presses were always coupled to the same tones. Participants were provided with a pen and a sheet of paper. Every time they registered a mistake, they had cross out one of a row/column/list of circles on the sheet.

Each observation trial started with a fixation cross of 500 ms. After an inter-stimulus interval of 1000 ms, an arrowhead was presented. It remained visible until the experimenter pressed one of the two buttons. 50 ms after the experimenter's response, the corresponding tone was presented. The next trial started after an inter-trial interval of 1500 ms.

The observation phase comprised 300 trials composed of the factorial combination of two pointing directions of the arrowheads and the accuracy of the experimenter's performance (i.e., 80% correct trials, 20% "mistakes"). Trials were presented in a randomized order. The action-effect mapping was counterbalanced across participants. So for half of the participants the right button-press elicited a high tone and the left button-press a low tone (Mapping A), whereas the action-effect mapping was reversed for the other half of the participants (Mapping B).

Test phase. The procedure for the test phase followed the one of Elsner's and Hommel's study (2001). The buttons were positioned in front of the participant, before the experimenter left the room. Participants were asked to discriminate between the presented tones and to react as quickly and correctly as possible by pressing one of the two buttons. Participants were randomly assigned to one of two stimulus-response (S-R) mapping conditions. In the compatible S-R condition, the S-R-mapping was the same mapping between response and tone as the participants had experienced in the observation phase. In the incompatible condition, the relation between action-effect mapping and S-R-mapping was reversed and participants had to respond to the tone with the opposite button press than the one associated with the tone in the observation phase. Responses had to be given within 2,000 ms. The inter-trial interval was 1500 ms.

The test phase consisted of 100 randomly ordered trials (50 high and 50 low tone). Half of the participants in each condition had experienced action-effect mapping A in the observation phase and the other half had experienced action-effect mapping B.

2.2 Results

Reaction times (RTs) were measured relative to the onset of the tones (see Figure 2 for means). Trials with incorrect responses, no responses, and trials with RTs deviating more than two standard deviations of the mean RT were excluded from the subsequent analyses. The 100 trials were divided into three blocks consisting of either 33 or 34 trials each. Mean RTs were calculated and submitted to an analysis of variance (ANOVA) with the between-subjects factor Compatibility (compatible, incompatible) and the within-subjects factor Block (1, 2, 3). The RT analysis revealed a main effect of Compatibility, $F(1, 22)=7.86$, $p=.01$, $\eta_p^2=0.26$, showing that the response latencies in the compatible group (371 ms) were significantly faster than latencies in the incompatible group (427 ms). There were no other significant effects (all other $ps > .25$).

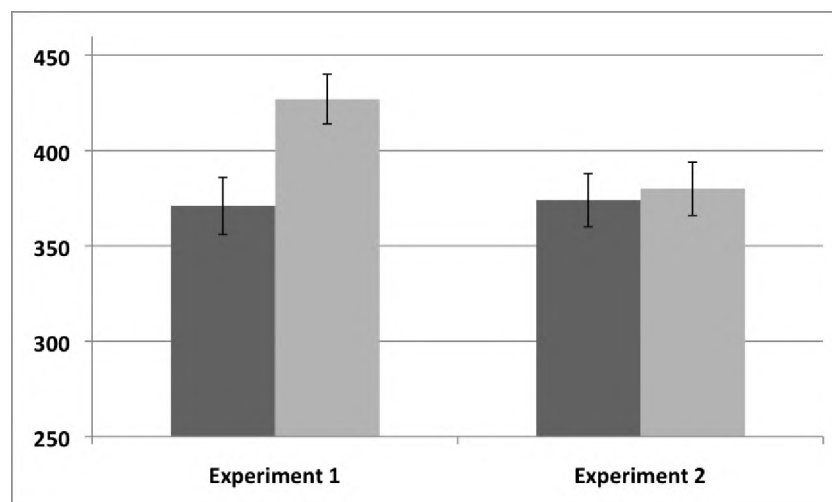


Figure 2. Mean reaction times in Experiment 1 and Experiment 2. Dark bars represent reaction times in the compatible, light bars in the incompatible conditions. Error bars indicate the standard errors.

2.3 Discussion

The aim of Experiment 1 was to investigate whether bidirectional action-effect associations can be acquired by observing other people's actions and the effects of those actions. It was

observed that participants pressed buttons faster when the stimulus-response mapping in a test phase was compatible with the action-effect mapping of another person's actions (i.e. in an observation phase) than when the stimulus-response mapping was reversed. This suggests that the observed action-effect contingencies affected participants' subsequent action execution and that participants thus had acquired action-effect associations through observational learning.

Experiment 2 was designed to investigate whether the observation of a real action is necessary to acquire novel action-effect contingencies or whether the mere belief that an observed effect was caused by another person's action would be sufficient (cf. Sebanz, Knoblich, & Prinz, 2005). To investigate this question, participants in Experiment 2 experienced the co-occurrences of two visual stimuli (i.e., yellow circles) on the right or left side of a computer screen, which was placed in front of them, and two auditory events (i.e., a low and a high tone). By means of a cover story, participants were lead to believe that the yellow circles on the left and right side of the screen indicated another human agent's left or right button presses (*belief instruction* condition). If participants indeed acquire action-effect associations through observational learning and if the mere imagination of an action is sufficient, one would expect the same effects as in Experiment 1. In other words, we would expect that participants associate the action with the subsequently presented auditory effect.

However, an alternative explanation for the faster response execution in the compatible condition of Experiment 1 could be that the participants merely associated two perceptual features; a spatial perceptual feature (e.g., left) with the particular tone (e.g., low tone). When this tone was presented again in the test phase, participants might have reacted faster with the corresponding button press because the perception of this specific tone primed actions on the side that had been associated with it. That would mean that participants' facilitated response execution was the result of a previously acquired association of visuospatial feature codes with different sounds (i.e., perceptual associations), rather than due to the acquisition of action-effect associations.

To exclude this possibility, half of the participants in Experiment 2 followed the same protocol as the participants in the *belief instruction* condition with the only difference that no cover story was presented to them (*computer instruction* condition). That means that the participants experienced the co-occurrences of the visual stimuli (i.e., yellow circles) and the auditory stimuli (i.e., tones) without linking these events to an action. If the effect of

Experiment 1 is only driven by an association of visuospatial feature codes with different sounds the *computer instruction* condition should result in the same pattern of effects (i.e., a facilitation for the compatible condition). If, however, the effect of Experiment 1, is due to the acquisition of action-effect associations, i.e., a specific button press leads to a specific auditory action effect, no facilitation effects would be expected for this condition between a compatible and a reversed condition.

3. Experiment 2

3.1 Method

3.1.1 Participants

A total of 48 students of the Radboud University Nijmegen (18– 33 years; 12 male) participated in the experiment in return for 8 euros or course credits.

3.1.2 Set-up and stimuli

In contrast to Experiment 1, participants were seated in front of a computer screen with no other person present in the room. In the screen, white left- or right-pointing arrowheads were displayed centrally on a black background. Additionally, a yellow circle appeared either on the right or left side of the screen. The interstimulus-interval (ISI) between arrowheads and the yellow circles was random, varying between 250 ms and 1250 ms (matching the confederate's performance in Experiment 1). Auditory effects and response buttons were the same as in Experiment 1.

3.1.3 Procedure and Design

Observation phase. The procedure was similar to Experiment 1. Instead of a human model pressing the right or left button as a response to the arrowheads, participants in both conditions of Experiment 2 (*computer instruction*, *belief instruction*) viewed yellow circles that were presented on the left or right side of a computer screen. Each appearance of a circle was followed by a tone. As in Experiment 1, participants were asked to indicate mismatches as in 20 % of the trials the right pointing arrowheads were followed by a circle on the left hand side and vice versa.

Importantly, the participants of the *belief instruction* condition were scheduled in pairs

of two people. When they arrived at the lab, they were told that they were going to perform a task together on two different computers. Each of them was brought into a separate room and subsequently instructed like the first half of the participants, with the important difference that they were told that the two yellow circles were caused by a button press of the other person. In other words, before the observation phase started, the experimenter demonstrated that the yellow circles could be caused by a button press (e.g., pressing the right button caused a circle to appear on the right side of the screen). Then they were told that in the first phase of the experiment their partner would perform a reaction time task, namely pressing buttons as a reaction to the arrowheads on the screen. Participants were told that their screen was an exact copy of their partner's screen so that they were able to see the arrowheads as well as their partner's reactions to them as indicated by the yellow circles.

Test phase. The test phase was identical to Experiment 1.

3.2 Results

Mean RTs were calculated and submitted to an analysis of variance (ANOVA) with the between-subjects factors Compatibility (compatible, incompatible) and Instruction (computer, belief) and the within-subjects factor Block (1, 2, 3). The analysis revealed a main effect of block, $F(2, 43)=7.76$, $p<.01$, $\eta_p^2=0.27$, but no main effect of Compatibility, $F<1$, or Instruction, $F(1, 44)=2.47$, $p=.12$, $\eta_p^2=0.05$, and no interaction effect between Compatibility and Instruction, $F<1$ (see Figure 1). As post hoc t -tests revealed, response latencies in the first block were significantly slower (390 ms) than latencies in the second block (369 ms) and the third block (371 ms), $t(47)=3.94$, $p<.001$ and $t(47)=3.07$, $p<.01$ respectively. This indicates that participants became faster over time, suggesting a practice effect.

To investigate whether the null effect in Experiment 2 was due to a lack of power, we performed a post-hoc power analysis (cf. Faul, Erdfelder, Lang, & Buchner, 2007). Given the conventional level of statistical significance of $\alpha=.05$ and a sample size of 48 participants, a post-hoc power analysis revealed an excellent statistical power of $(1-\beta) = .98$ for the detection of a compatibility main effect of $\eta^2=0.23$ (i.e. that is in the same size than the effect observed in Experiment 1). This suggests that the power of Experiment 2 was large enough to detect possible differences between the conditions.

3.3 Discussion

The results of Experiment 2 show that participants did not react faster in the compatible than in the incompatible condition – neither in the *Computer instruction* condition nor in the *Belief instruction* condition. This suggests that no bidirectional action-effect-association was acquired.

In particular, the aim of Experiment 2 was two-folded. First, it was examined whether the acquisition of an association between tones and the spatial perceptual features of left and right affected the subsequent responses to buttons on the left and right side of the participant, when responses were produced due to signalling by the tones (*Computer instruction* condition). Second, we tested whether the mere belief that these spatial perceptual features were the consequences of another person's actions allowed participants to acquire action-effect associations through observational learning and whether participants reacted faster in a compatible condition than in an incompatible condition (*Belief instruction* condition).

The fact that participants did not react faster in the compatible compared to the incompatible condition allows two conclusions: first, a perceptual priming of the spatial features left or right does not lead to a facilitation of an action in the left or right action space. This suggests that the participant's faster reaction in the compatible condition of Experiment 1 cannot be due to simple perceptual priming of a previously acquired association between a tone and a visuospatial feature, but is due to the acquisition of action-effect contingencies. Second, only the belief that a stimulus event on the left or right hand side of a screen and the subsequently presented tones are the consequences of another person's actions, does not lead to the acquisition of action-effect associations. This finding highlights the significance of real action observation and their effects.

4. General Discussion

The present study shows that bidirectional action-effect associations can also be acquired through the observation of other people's actions and their effects and thereby extends the ideomotor approach to the realm of observational learning. In the following paragraphs the implications of the present findings for notions regarding the acquisition of stimulus-response (S-R) mappings and for social learning theories will be discussed.

In the past decades research has provided plenty of evidence that humans are able to

acquire S-R mappings (for an overview see Ormrod, 1999). Furthermore, recent research has shown that an acquired action-effect mapping affect participants' subsequent performance in a S-R task, when the previous effect of an action served as the stimulus to which participants had to respond with the same action (Elsner & Hommel, 2001; Kunde et al., 2002). Our study adds to these results the finding that also observed actions performed by others and their effects affect subsequent S-R tasks. Importantly, these effects are only present when the associations are experienced in an action-context. The absence of this effect in the second experiment, in which participants merely believed or imagined that an outcome was caused by another person's action, indicates that only an observed action leads to the activation of a motor code in the observer's cognitive system, which could subsequently be related to the representation of the action's effect. This corresponds to recent findings that suggest that a pure imagination of a goal-directed action does not lead to an action representation that is comparable to the observation of a goal-directed action (Caettano, Caruana, Jezzini, & Rizzolatti, 2009). Together, our results extend thus classical learning theories by showing that associations between actions and their sensory consequences are bidirectional and that the perception of a previous action effect has an impact on subsequent behavior.

Our finding has important implications for social learning theories (e.g., Bandura, 1977; Miller & Dollard, 1941), as it suggests a cognitive mechanism that enables humans to learn through the observation of others' actions. Whereas previous research has shown that humans are able to learn through observation (e.g., Cross et al., 2009), the cognitive basis behind this ability has remained largely unclear. In other words, how can people learn through the observation of other people's actions and the consequences of these actions, enabling them to avoid costly learning by trial and error? Based on our current findings we suggest that the acquisition of bidirectional action-effect associations might be a crucial mechanism that allows humans to acquire novel action knowledge through the observation of others' actions.

In particular, we suggest that the perception of an action leads to the activation of the same motor code in the observer's own motor repertoire. When the effect of this action is perceived concurrently with the action, the representation of the effect (perceptual code) will be associated with the activated motor code, leading to the acquisition of a novel action-effect association (cf. Paulus, Hunnius, Vissers, & Bekkering, in press-b). When on a later occasion the same effect is perceived or intended and the perceptual code is thus activated, the associated motor code will also be activated, leading to or facilitating the execution of the

action (Hommel et al., 2001). We propose that the acquisition of bidirectional action-effect associations through observational means might play an important role in the uniquely human ability for social learning and imitation of such different behaviours, such as aggressive behavioural tendencies in children (e.g., Bandura, Ross, & Ross, 1961) or the acquisition of novel action knowledge as already seen in infancy (Elsner & Aschersleben, 2003; Paulus et al., in press-c). Future research is needed to examine the scope and limitations of this cognitive mechanism as well as possibly differences between observationally acquired action-effect associations and the ones that are acquired through active action experiences.

In sum, the present study demonstrates an influence of observed action-effect contingencies on own action execution. Our results suggest that bidirectional action-effect associations can be acquired via observation and that this cognitive mechanism might underlie the human ability for social learning.

Chapter 10

How do infants learn through the observation of others' actions?

A study on the neural basis of social learning in infancy



Based on:

Paulus, M., Hunnius, S., & Bekkering, H. (in prep.). *How do infants learn through the observation of others' actions? A study on the neural basis of social learning in infancy.* Manuscript in preparation.

Abstract

Transmission of knowledge is one of the reasons for human evolutionary success. Research has provided evidence that already human infants possess eminent social learning abilities. However, the neurocognitive mechanisms subserving this ability are unknown. We propose that infants' social learning is based on the acquisition of bidirectional action-effect associations through observation. In line with this, we demonstrate that 8-month-old infants display motor activation when they perceive a sound that had previously been the effect of another person's action, but not when the sound was learned outside an action-observation context, or was not presented before at all. This suggests that learned associations between cortical motor areas and areas that are involved in the processing of perceptual effects form the neural basis of social learning in infancy.

1. Introduction

The human ability for the intergenerational transmission of knowledge is considered one of the reasons for human evolutionary success (Gould, 1979). Importantly, unlike members of most other species (e.g., Thorndike, 1911), humans already possess eminent social learning capabilities in infancy (Moore, 2006; Tomasello, Carpenter, Call, Behne, & Moll, 2005). Striking examples of early social learning are provided by studies on infants' imitation. These behavioral studies show that from early on in life, infants are able to learn from the observation of others' actions (e.g., Elsner & Aschersleben, 2003; Meltzoff, 1988; Piaget, 1962). But which neural mechanisms enable social learning in infancy?

It has been suggested that the acquisition of novel action representations is based on learned associations between motor codes and effect codes (i.e. bidirectional action-effect associations; e.g., Del Giudice et al., 2008; Elsner & Hommel, 2001; Keyers & Perrett, 2004). For example, when someone cracks a nut, he also perceives the sound resulting from this action. By means of Hebbian learning, the motor code and the effect code become associated. It has been suggested that such action-effect associations underlie the voluntary control of actions (Hommel, Müsseler, Aschersleben, & Prinz, 2001). Furthermore, if the typical sound associated with the action is perceived at a later date, this leads to an activation in the motor system (i.e. motor resonance), indicating the existence of an action representation. Empirical support for this mechanism comes from studies on human action control (Elsner & Hommel, 2001) and the mirror neuron system (MNS; Rizzolatti & Craighero, 2004). For example, it has been shown that the premotor cortex in macaque monkeys is not only active when they perform a hand action, but also when they hear the typical action-related sound (e.g., cracking a peanut; Kohler et al., 2002). However, research has so far mainly concentrated on the acquisition of action knowledge through first-hand action experiences.

Human infants are also already able to acquire novel action representations by observation. We propose that the mechanism, which subserves this ability is the acquisition of action-effect associations through the observation of others' actions and their consequences. On a neuronal level, this should be implemented as associations between brain areas that are involved in motor control and areas that are involved in the processing of perceptual effects (Elsner et al., 2002; Melcher et al., 2008). Following this theoretical notion, we hypothesize that infants should also display cortical motor activation when they

perceive a sound that has previously been the consequence of another person's action. To investigate this hypothesis, we performed an EEG study with 9-month-old infants.

2. METHOD

2.1 Participants

The final sample consisted of 11 infants (*range*: 8 months, 25 days to 9 months, 24 days; average: 287 days; 4 boys). Seven infants were tested but not included in the final sample due to equipment failure (n=1), parental interference (n=2) or fussiness (n=4). Participants were recruited from public birth records and were healthy, full-term infants without any pre- or perinatal complications. Informed consent for participation was given by the infants' parents. The families received a baby book or monetary compensation for their participation.

2.2 Stimuli

The experimental material of the training phase consisted of three identical cylindric objects (d= 4.5 cm; h= 6 cm; see Figure 1) as well as voice recorders (Voicetracer 600, Philips, Germany). The cylindric objects were made out of red plastic. They could be used as rattles and produced three different sounds when shaken (due to their content which could be a bell, a couple of metal disks or screws). Each voice recorder contained a recording of one of the three sounds, so that they could be played to the infants. The voice recorders were inserted into cylindrical plastic boxes that served as containers. This enabled parents to put the voice recorders on the table in a stable position.



Figure 1. Figure 1 shows the objects used in the training phase of the study, the rattle (left) and the container in which the voice recorder was inserted (right).

The stimulus material of the test phase consisted of recordings of the same three sounds. Each stimulus lasted for 2000ms. The auditory stimuli were recorded digitally using a MOTU 828ml2 audio interface on a MacPro and an AKG-3000 condenser microphone. Recordings were made in an acoustically isolated room at 16-bit, 44,100 KHz quality. They were controlled for pitch and loudness. To maintain the child's attention and to avoid head movements during in the test phase, geometric shapes were presented randomly as background pictures on a computer screen.

2.3 Procedure and Design

Training Phase. Infants and parents were visited at home by the experimenter and handed over one of the rattles and one voice recorder. Parents were instructed about the training procedure verbally and by means of a written training schedule. They were asked to train their infant for 5 minutes each with the rattle and the voice recorder for 7 consecutive days. The rattle training consisted of shaking the rattle in front of the infant at a distance of approximately 1 to 2 meters, which would be close enough to ensure the infant's attention but out of his or her reach. For the training with the voice recorder, the container was placed at

approximately the same distance. It was switched on by a caregiver so that the sound was played. Parents were instructed to remove any other toys from the infant and to avoid any other sounds in the background (e.g., radio) during the training with the rattle and the voice recorder. To ensure compliance with the instructions, parents were asked to confirm the exact training times every day on the printed training schedule and provide information about how their infant reacted to the stimuli.

It was counterbalanced within participants and between days with which object the training started (i.e. rattle or voice recorder). Moreover, it was balanced between participants which of the three sounds served as the action-related sound (AS; caused by shaking the rattle), the non-action related sound (NAS; played from the voice recorder), and the control sound (CS; not used during the training phase).

Test Phase. The study was set up as a within-subjects design and participants were presented with all three auditory stimuli. The test session was scheduled one day after the last training session. During the EEG measurement session, the infant was seated in an infant seat that was placed in front of a computer monitor. The parent was sitting behind the infant. A loudspeaker was located behind the screen. The three auditory stimuli (i.e. AS, NAS, CS) were presented in a pseudo-randomized order (i.e. the same stimulus was never presented more than two times in a row) using the software Presentation 11.07 (Neurobehavioral Systems, USA). The abstract geometrical figures were displayed on the screen in a random order that was unrelated to the auditory stimuli. The experiment was conducted until the child lost attention, started crying or fell asleep. During the test phase, video recordings of the infants were made.

EEG was recorded using an infant-size cap with 30 active Ag/AgCl electrodes (EasyCap, Germany) with a layout following the 10/20 system using a BrainAmp AC amplifier with a band-pass filter of 0.1-125 Hz at a sampling rate of 500 Hz. All electrodes were referenced online to a central reference electrode and rereferenced offline to an average over all electrodes. EEG data was analyzed using Brain Vision Analyzer (Brain Products, Germany).

2.4 Analysis

As the stimuli were presented for 2000 ms per trial, the EEG data was segmented into 2000 ms time frames per trial for further analysis. Trials with artifacts were rejected by means of the automatic artifact rejection function of Brain Vision Analyzer (maximum difference of values in a segment 300 microvolt). On average, 14% of all trials were excluded from further analysis, leaving on average 26.8 trials per infant and per condition. A two-way repeated measures analysis of variance (ANOVA) with the within-subject factors Hemisphere (C3, C4) and Sound Condition (AS, NAS, CS) and number of included trials as dependent variable revealed only a significant effect of Hemisphere, $F(1,10)=8.226$, $p<.05$ (all other $ps > .47$), showing that more trials were recorded for C3 ($M = 25.9$, $SE = 2.4$) than for C4 ($M = 27.9$, $SE = 2.8$). Fast Fourier transformations (FFTs) were conducted over each trial and grand averages were calculated for all three conditions (AS, NAS, CS). For the analyses, we selected the C3 and C4 electrodes as they are located above the left and right hemispherical cortical motor regions. Mu-frequency power was averaged over the 6 to 9 Hz frequency band (Nyström et al., in press; Reid et al., 2011). Data were entered into a two-way repeated measures analysis of variance (ANOVA) with the within-subject factors Hemisphere (C3, C4) and Sound Condition (AS, NAS, CS).

To ensure that the differences in mu desynchronization between conditions were not due to differences in active movements, we coded infants' movements from the video recordings. The data were analyzed on a frame-by-frame basis. Infants' movements of the hands and other limbs were coded for each trial on a four point scale (0: no movements; 1: low activity; 2: medium activity; 3: high activity; cf. Reid et al., 2011). Hand movements were included as a separate variable as during the training phase the rattle sound might have been connected to the motor program of the hands so that the perception of the rattle sound might have facilitated hand movements (e.g., Gazzola, Aziz-Zadeh, & Keysers, 2006). For statistical analysis, the data of the two dependent measures (hand and other limb movements) were entered into a multivariate analysis of variance (MANOVA) with the within-subjects factor condition (AS, NAS, CS).

3. Results

The analysis revealed only a significant main effect of Sound Condition, $F(2,20)=6.651$, $p<0.01$, $\eta_p^2=.40$ (all other $ps>.40$; see Figure 2). For further analysis, the data were averaged across hemispheres (see Figure 3). Post-hoc t-tests revealed that mu-desynchronization was stronger in condition AS compared to the conditions NAS and CS, $t(10)=3.010$, $p=.01$ and $t(10)=3.078$, $p=.01$, respectively, whereas no significant difference was found between the latter two conditions, $t(10)=0.098$, $p=.92$. This shows that infants' perception of a sound that had previously been the effect of another person's action led to an activation of their motor system. The MANOVA on infants' movements yielded no significant effect ($F<1$).

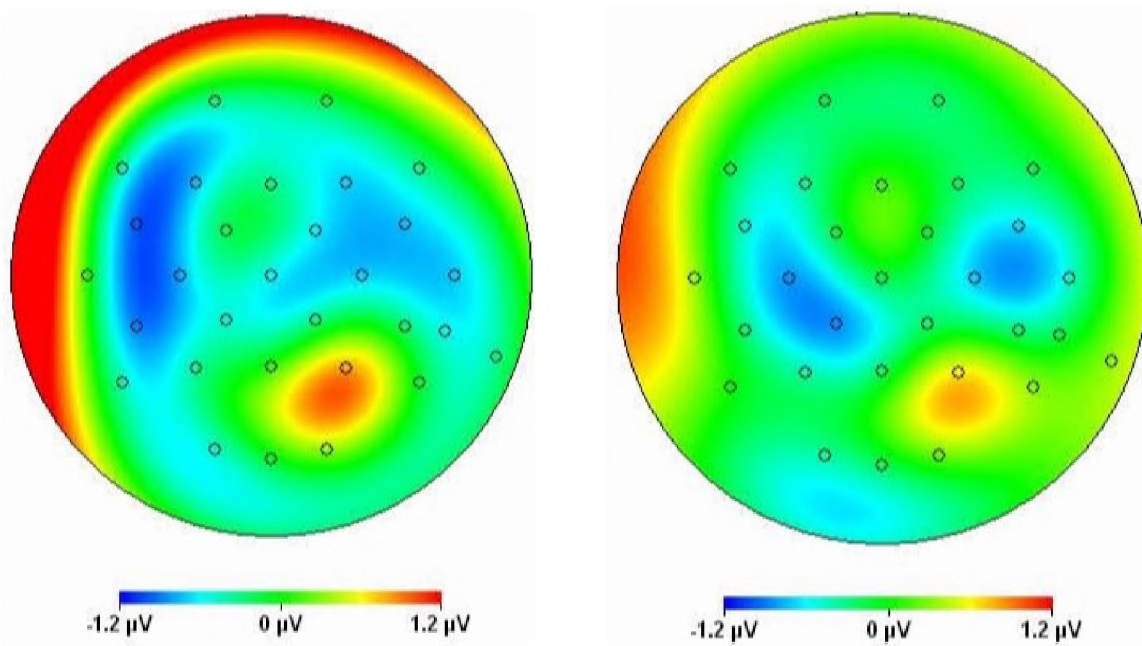


Figure 2. Topographic maps representing the differences in the EEG power spectrum between perception of AS and NAS (left picture) as well as AS and CS (right picture) in the mu-frequency band (6-9 Hz).

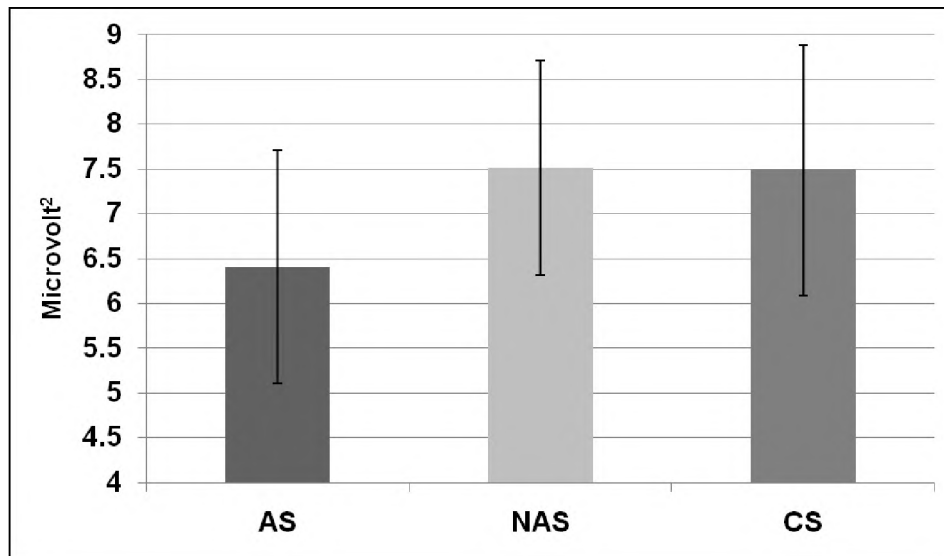


Figure 3. Figure 3 displays the grand averaged EEG power for the mu-frequency band (6-9 Hz) for the three auditory stimuli AS (dark grey bar on the left), NAS (light grey bar in the middle), and CS (grey bar on the right) over the C3 and C4 electrode sites.

4. DISCUSSION

We interpret this finding as evidence for the claim that infants acquired a novel action-effect association through observing another's action. Furthermore, our result suggests that the neural basis of this mechanism is learned association between cortical motor areas and areas that are involved in the processing of perceptual effects

Importantly, our result cannot be explained by differences between the three auditory stimuli, as their use as AS, NAS, and CS was counterbalanced between participants. Additionally, the fact that the desynchronization was significantly stronger for the action-related sound compared to both another familiar sound the unfamiliar sound excludes the possibility that the desynchronization was merely due to a familiarity or a novelty effect. Finally, there were no differences in infants' movements between the conditions. It suggests that the differences in mu-desynchronization cannot be explained by actual differences in overt behavior.

Previous studies have shown that children (e.g., Eenshuistra, Weidema, & Hommel, 2004; Kray, Eenshuistra, Kerstner, Weidema, & Hommel, 2006) and even infants (e.g.,

Verschoor, Weidema, Biro, & Hommel, 2010; see also Chapter 3 of this thesis) are able to acquire bidirectional action-effect associations. Furthermore, it has been suggested that the acquisition of these associations plays an important role in intentional action control (Elsner, 2007; Hommel et al., 2001). Whereas previous studies have suggested that infants indeed use knowledge about observed action effects in their subsequent action performances (e.g., Elsner & Aschersleben, 2003; Hauf & Aschersleben, 2008), it remained unclear if infants are able to acquire action-effect associations through observational learning (as adults likely do; cf. Chapter 9 of this thesis). The present findings adds thus to recent research by providing evidence that infants of 9 months of age acquire novel action-effect associations through observing the actions of others and their effects.

In particular, we suggest that the infants, while observing another person's rattle action, 'mirrored' the action within their own motor repertoire (i.e. activated the corresponding motor code). When they perceived the sound effect of the rattle action, their representation of the effect became associated with the activated motor code (i.e. they acquired an action-effect associations). Subsequently, upon perceiving the rattle's sound, it resulted in an activation of cortical motor areas (cf. Elsner et al., 2002; Melcher et al., 2008) and thus a desynchronization in the mu-frequency band (cf. Marshall & Meltzoff, 2011).

This study is the first to examine the neural mechanisms that underlie social learning in infancy. It provides direct evidence that infants are able to acquire bidirectional action-effect associations not only through their own first-hand action experiences, but also through the observation of others' actions. As such bidirectional associations between actions and their effects underlie voluntary action control (Elsner & Hommel, 2001; Hommel et al., 2001), infants' acquisition of such associations through observation enables them to use socially acquired knowledge for their own action control, e.g. when imitating the observed action (Paulus, Hunnius, Vissers, & Bekkering, in press-b). We suggest that this mechanism may form the basis of human infants' unique ability for social learning.

Chapter 11

Summary and Epilogue



SUMMARY AND EPILOGUE

„Those who make a practice of comparing human actions are never so perplexed as when they try to see them as a whole and in the same light; for they commonly contradict each other so strangely that it seems impossible that they have come from the same shop.“

(Michel de Montaigne, 1965, p. 239)

Summary and Epilogue

How do children perceive others' actions? How do they process all the different movement-related information? How do they use this information to guide their own behavior? How do they, in the course of development, finally come to understand the intention behind an action? These are by no means trivial questions and are far from being conclusively understood in current psychological research.

The importance of action perception in early social-cognitive development has frequently been stressed. For example, it has been suggested that the development of action perception is related to a later understanding of humans as intentional (Barresi & Moore, 1996) and mental beings (Aschersleben, Hofer, & Jovanovic, 2008; Henning, Daum, & Aschersleben, 2009). Furthermore, the ability to predict others' action is a prerequisite for smooth interactions with them (cf. Bekkering et al., 2009; Sebanz, Bekkering, & Knoblich, 2006). Finally, a close observation of others' behavior allows us to learn from others by imitating them and thus to acquire novel knowledge without costly learning through trial and error (e.g., Byrne & Russon, 1998).

Importantly, developmental research has shown that already very young infants are attentive to others' actions (Moore, 2006). Further insight into children's developing action perception has been provided over the last decade. It has, for example, been suggested that infants are already sensitive to different components of intentional action such as the goals of others' actions (Woodward, 1998) and the particular way in which those goals are achieved (Behne, Carpenter, Call, & Tomasello, 2005; Daum, Sommerville, & Prinz, 2009). Furthermore, it has been shown that infants are able to anticipate the targets of others' actions (Falck-Ytter, Gredebäck, & von Hofsten, 2006) and learn from the observation of others' actions (Elsner & Aschersleben, 2003; Hauf, Elsner, & Aschersleben, 2004). Notwithstanding these insightful findings, the neurocognitive mechanisms that subserve

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infants' processing of others' actions have remained a topic of intense theoretical discussion over the past few years (e.g., Biro & Leslie, 2007; Daum et al., 2009; Elsner, 2007; Gergely & Csibra, 2003; Gredebäck & Melinder, in press; Hauf, 2007; Meltzoff & Moore, 1989; Moore, 2006; Sodian, 2011; Tomasello, 1999; Woodward, Sommerville, & Guajardo, 2004). The main aim of this thesis was thus to examine in greater detail some of the most influential theories at the present time with regard to infants' processing of others' actions.

Below, I first summarize the thesis and its main findings, and then discuss the implications of this work for future research. Finally, I will present the conclusion of this thesis.

1. Summary

After the theoretical introduction provided in Chapter 1, Chapter 2 reports on a study that investigated infants' and adults' prediction of an agent's behavior by measuring their anticipatory eye movements. In particular, this study aimed to investigate the impact of two proposed neurocognitive mechanisms – frequency learning and teleological reasoning – on human action prediction. The results suggested that infants' anticipations are based on the frequency of previous events; i.e. they expected that an agent would continue with an action that he had already carried out several times, but infants would not evaluate the efficiency of the possible actions. The results for the adult population also studied in this paradigm, were less clear. Initially, their anticipations were based on the previous actions of the agent, but this pattern rapidly changed over time. Whereas this study provides evidence for the impact of frequency learning on infants' action prediction, adults go beyond this; their gaze behavior might rely on teleological reasoning.

In Chapter 3 the impact of 8-month-old infants' active action experiences on their subsequent action perception was examined in an EEG experiment. After one week of training with a novel rattle, infants displayed more motor activation when they heard the sound of that rattle than when they heard either another familiar sound or a novel sound, which were not action related. This study provides experimental evidence that active action experiences play a role in the processing of others' actions. Furthermore, it suggests that the development of motor resonance is based on acquired associations between actions and effects.

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Chapter 4 presents a study on 14- and 20-month-old infants' prediction of the target of another person's tool-use action. It was investigated whether infants initiate anticipatory eye movements based on the information about an actor's grasp and the orientation of the tool. The results show that the 20-, but not the 14-month-old infants were able to flexibly predict the action's target on the basis of these cues. As infants as young as 9 months are already able to learn about statistical regularities (e.g., Fiser & Aslin, 2002), this finding suggests that frequency learning is not the major mechanism underlying infants' behavior in this task. As infants' own tool-use abilities unfold over the second year of life, the findings are in line with the notion that infants' use of these cues can only be realized in congruency with their own tool-use abilities.

In Chapter 5, the development of children's ability to judge others' action capabilities was investigated in 2.5-, 3.5-, and 5-year-old children. Employing a 'choice' task it could be shown that 3.5-year-old children were able to correctly evaluate others' action capabilities. Additionally, even though the 3.5- and 5-year-olds performed at approximately the same level in the 'choice' task, the 5-year-old children clearly outperformed the younger children in their ability to justify their choice. It has been argued that the perception of others' action capabilities is based on the perception of others' affordances for action (Ramenzoni, Riley, Shockley, & Davis, 2008). Following this line of reasoning the present study suggests that this mechanism develops over the third year of life. Furthermore, it provides evidence that this is initially a practical ability that only becomes theoretically reflected in the course of their further development.

Chapters 6 and 7 report on two studies that examined the impact of motor resonance and teleological reasoning. They investigated whether 14-month-old infants' imitation can be best explained by a sensorimotor matching process between the model's actions and the infants' motor repertoire ('motor resonance'), or rather by infants' evaluation of the efficiency of others' actions. To this end, both factors were manipulated in the two studies. The results suggest – in line with Chapter 2 – that rational reasoning does not have an impact on infants' imitative behavior, but instead provide evidence for the role of motor resonance.

Chapter 8 formalized the theoretical approach of the previous two chapters by suggesting a model of imitation in infancy. This model proposes that infants' imitation is based on the interplay between two mechanisms: motor resonance and action-effect-binding. Two hypotheses were derived from the model and empirically investigated. First, it was

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hypothesized that infants should not imitate an action in the absence of a salient action effect even when it induces high motor resonance. Second, it was hypothesized that infants should not imitate an action that induces little motor resonance, even when followed by a salient action effect. The results were in line with the predictions derived from the model, supporting the view that motor resonance and action-effect-binding play an important role in infants' action perception.

Chapter 9 extends the observational learning findings of Chapters 6, 7 and 8 to adults. By means of a reaction time task, it investigated whether participants are able to acquire bidirectional action-effect associations through observational learning only. To this end, participants observed how a model repeatedly pressed two buttons, which led to the production of a specific tone. In a subsequent test phase, participants were faster when they had to perform the same button press as a response to the sound that was previously produced by this effect than when this mapping was reversed. This indicates that the perception of the sound activated a specific motor code and that participants were thus able to acquire a bidirectional action-effect association by observational learning.

In Chapter 10, the neurocognitive mechanisms underlying infants' ability for social learning were investigated by means of an EEG study. Based on the results of Chapters 6 to 9 it was hypothesized that infants should be able to acquire novel action-effect associations by means of observational learning. For seven consecutive days, 9-month-old infants observed a caregiver playing with a rattle that produced a specific sound, but did not get the opportunity to play with the rattle themselves. After this training phase, infants' electrophysiological responses were recorded. The participants displayed more motor activation when they were presented with the sound made by this rattle compared to two other sounds that were either as familiar as the rattle sound or totally novel. This shows that infants associated the sound of the rattle with a motor program through observational learning. It is suggested that this mechanism might underlie infants' ability for social learning.

Taken together, the studies reported in this thesis provide support for the notions that perceptual learning processes, particularly frequency learning (Chapter 2) and affordance perception (Chapter 5), play an important role in children's action perception rather than the perceived rationality of others' actions (Chapter 2). Furthermore, it could be shown that infants rely on their own action experiences to process others' actions (i.e., motor resonance; Chapter 3) and that this mechanism very likely also plays a role in children's action

prediction (Chapter 4). Finally, the studies on imitative and observational learning suggest that infants' imitation is based on both motor resonance and action-effect binding (Chapters 8, 10) rather than a rational evaluation of others' actions (Chapters 6, 7). This mechanism probably also plays a role in adults' observational learning (Chapter 9). The following section will discuss the contribution of these findings for a theory of developing action perception and implications for further research.

2. Contribution to a psychology of developing action perception

The main aim of this thesis was to investigate the development of action perception in infants and young children and, in particular, its underlying neurocognitive mechanisms. What picture of development is given by the results of the studies that were reported in this thesis? What is their contribution to a theory of developing action perception?

The findings of this thesis coincide with the claim that sensorimotor processes play an important role in young children's processing of others' actions. On the one hand, evidence was provided that the learning of visual associations subserves infants' ability to predict others' actions. On the other hand, several studies showed an impact of infants' own action experiences and action capabilities on their processing of others' actions and their imitative learning, stressing thus the role of motor processes for action perception. Additionally, it could be shown that perceptually salient action effects are important in guiding infants' imitation, which suggests that infants like to reproduce interesting (i.e. stimulating) events. In contrast, no evidence could be found for the claim that infants' action perception is subserved by an ability to assess the efficiency of others' actions. These findings are in line with theoretical notions that propose that the early development of social cognition is based on sensorimotor couplings and that more advanced social-cognitive abilities develop out of these more basic processes (e.g., Barresi & Moore, 1996; Bibok, Carpendale, & Lewis, 2008; Piaget, 1962; Thelen, 2000; see also Müller & Overton, 1998).

Interestingly, the studies suggest that domain-general and domain-specific mechanisms are involved in children's developing action perception. On the one hand, associative learning about the frequency of others' actions is based on infants' capacity for statistical learning, which is a domain-general process that plays a role in every kind of event perception. On the other hand, evidence was provided for the impact of domain-specific mechanisms such as motor resonance or affordance perception. Accordingly, one theoretical

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conclusion of this thesis is that future research should abandon the research question, if domain-general or domain-specific processes are underlying young children's action perception. Rather, it should be investigated, which domain-general and which domain-specific mechanisms emerge and are important during different phases of development.

The results show that these sensorimotor processes are also relevant in adults' action perception, that is, throughout the entire life span. In particular, also adults might predict actions on the basis of frequency information (see also Boseovski & Lee, 2006, for a study with preschoolers). Additionally, motor resonance and action-effect binding plays a role in adults' observational learning, too. The findings of this thesis are thus in accordance with embodied cognition approaches, which stress the sensorimotor basis of human cognition (e.g., Fischer & Zwaan, 2008; Glenberg, 2010)

The studies also suggest that more complex forms of action understanding such as the perception of others' action capabilities or the ability to assess the efficiency of an observed action develops at a later age and are not in place during infancy (see also Daum et al., 2011; Klossek, Mazzotta, & Puri, 2010; Pfeifer & Elsner, 2011). With respect to the ability to assess others' action capabilities the results of this thesis are in accord with other findings that this ability develops around 3 years of age (see Rochat, 1995). Furthermore, whereas the present studies suggest that infants around 1 year of age do not reason about the efficiency of others' actions, it does not give a definitive answer about the developmental trajectory of this ability. However, as an assessment of the efficiency of another person's action rests conceptually upon the capacity to perceive his or her action capabilities (because to be able to evaluate whether someone has acted in the for him/her most efficient way to attain a goal we need to know if he would have been able to perform another action to reach the same goal⁸), there is reason to assume that also this ability may not develop before 3 years of age (but, for a different claim see, for example, Zmyj et al., 2009).

Why might this be the case? It may be speculated that the direct perception of an action activates the related perceptual and motor processes that subserve the processing of

⁸ Interestingly, within comparative psychology it has been claimed that also chimpanzees (and dogs; Range et al., 2007; but see Kaminski et al., 2011) imitate rationally (i.e., reason about the efficiency of others' actions; e.g., Buttelmann et al., 2007), whereas they lack the ability to perceive others' action capabilities (Vonk & Subiaul, 2009). It remains a puzzling question, how chimpanzees might be able to judge the relative efficiency of means, if they are not able to perceive others' action capabilities.

this action. In contrast, the perception of others' action capabilities is not the processing of an ongoing action, but a rather abstract processing of what somebody may be able to do. This, however, is a cognitively more complex task as one has to deal with several possible events – instead of just processing one ongoing action. In a similar vein, the evaluation of the efficiency of others' actions rests upon a number of other cognitive competencies, including the ability to think counterfactually (e.g., when reasoning that somebody could have acted more efficiently to attain a certain goal), which does not develop before the preschool age (cf. Rafetseder, Cristi-Vargas, & Perner, 2010). These considerations suggest that the development of these more complex forms of action perception (and understanding) is related to and probably depends on the development in other psychological domains such as representational development (cf. Barresi & Moore, 1996; Moore, 2006) and/or the engagement in narrative practices (cf. Hutto, 2008). Further research is needed to investigate the developmental onset of complex forms of action understanding and how it develops out of sensorimotor based forms of action perception.

3. Implications for further research

One of the central questions of this thesis concerned the ability to evaluate others' actions in terms of efficiency. It has been proposed that this is a central ability as it allows humans to predict others' movements (when the action's goal is known) or their action goals (when the movement path is known). Furthermore, it has been claimed that this ability is based on a cognitive core principle and is already present as early as 6 months of age (Gergely & Csibra, 2003). Several studies presented in this thesis systematically examined this claim, but could not find any support for this theory. Rather, the findings suggested a number of alternative explanations to account for the previous findings that claimed evidence for infants' rational action perception. This thesis therefore questions the claim that already infants evaluate others' actions in terms of their efficiency, and limits therefore the theoretical impact of the *Theory of Rational Action* (Gergely & Csibra, 2003). The precise developmental pathway of this ability needs therefore further investigation. Importantly, the findings of this study do not rule out the possibility that this ability is evolutionary inherited and becomes functionally relevant only at a later age. On the other hand, it could also be possible that this ability is the result of cultural socialization processes (cf. Hutto, 2008). One way of disentangling the contributions of phylogenetic and cultural processes might be to conduct culturally comparative research. If humans' ability and propensity to reason about others' actions in

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terms of efficiency is unaffected by the cultural context, one would expect that children should show this ability at around the same age in all cultures. However, if the sociocultural context plays an important role, variations between cultures should be expected.

The model of imitative learning in infancy presented in Chapter 8 suggests that infants' imitation is based on the interplay of two processes: motor resonance and action-effect binding. Interestingly, already in the first half of the 20th century, developmental psychologists discussed the question of how human infants were able to imitate others' actions or, in other words, how infants relate others' actions to their own action repertoire, especially when they are not able to visually perceive their own action. Guillaume (1925) suggested that a perceived action might serve as a signal that induces the same action in the infant, as perceived and executed action have been related to each other by means of associative learning when the infant executes an action and perceives the visual consequences of his own action. Piaget (1962), however, proposed that the perceived action serves as an index that allows the infant to assimilate the other's action to their own (invisible) action. Continuing this discussion, Meltzoff and Moore (1989) suggested that infants are able to relate perceived and executed actions by means of an intermodal matching scheme (but see also Anisfeld, 1991). The presented findings are informative for this debate because they are in contrast with all three aforementioned theories, which claimed that the perception of an action leads to a direct imitation of the perceived action. The findings stress – in line with other research (e.g., Elsner, 2007; Verschoor, Weidema, Biro, & Hommel, 2010; see also Bekkering, Wohlschläger, & Gattis, 2000) – the motivational aspects of infants' imitation: infants want to attain a goal, typically to retrieve an interesting effect. Furthermore, with regard to the origins of the ability to relate others' actions to one's own motor repertoire, Chapter 3 of this thesis suggests that learned associations between actions and effects might play an important role and is thus in line with the considerations put forward by Guillaume (1925). However, this thesis does not tackle the question of how the presented mechanisms interact, during the course of children's development, with other factors like pedagogical cues (Csibra & Gergely, 2009) or the social context (Carpenter, 2010).

It has been proposed that the perception of others' affordances plays a central role in the perception of others' actions (e.g., Mark, 2007; Stoffregen, Gorday, Sheng, & Flynn, 1999). In particular, convincing arguments have been provided, which suggest that the perception of others' action capabilities may be subserved by affordance perception mechanisms (Ramenzoni et al., 2008). In more detail, it has been proposed that humans are

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able to directly perceive the actions that objects afford for another person and that they are by means of this mechanism able to perceive the other's action capabilities. This thesis presents first evidence that the ability to perceive others' action capabilities develops around 3 years and suggests that the perception of others' affordances might therefore be a developmental achievement of this age. However, the present research was restricted to an identification of this developmental trajectory and it remains for further research to investigate why this ability develops at this age. One possibility could be that this development crucially depends on the development of other abilities such as inhibitory control and executive functioning, which develop around this time (see Zelazo & Müller, 2002, for a review). More precisely, a judgment of the actions that objects afford for others requires that the child is able to prescind from the affordance the objects present for him. Such an ability to suppress concurrent and more salient information in order to focus on another task is commonly related to executive functioning, which in turn is thought to rely on the development of the prefrontal cortex. Further neurocognitive research is necessary to investigate this hypothesis.

In her framework theory of cognitive evolution, Heyes (2003) differentiated between phylogenetic and ontogenetic processes as well as between constructive and inflective processes in the genesis of novel cognitive capacities. Whereas the former distinction refers to the source of the selection process, which could be based either on natural selection or on developmental selection, does the latter distinction refer to the locus of change, which could be either a cognitive mechanism itself or the specific input to a mechanism. In light of this framework, the present results stress the relevance of ontogenetic inflective processes in children's action perception. More precisely, perceptual learning and motor resonance can be classified as ontogenetic and inflective, as they both rely on existing cognitive mechanisms, which become biased to specific inputs in the course of development. The case of affordance perception is less clear, but the fact that affordance perception depends crucially on action experiences (e.g., Franchak, van der Zalm, & Adolph, *in press*) suggests that this mechanism is also based on ontogenetic processes. Importantly, the present thesis therefore limits the potential theoretical impact of the nativist claims of domain-specific reasoning theories that proposed that young children's processing of others' actions is based on mechanisms that evolved in processes of phylogenetic construction (e.g., Baron-Cohen, 1997; Csibra & Gergely, *in press*). Clarifying whether and how phylogenetic processes or innate competences contribute to children's developing action perception thus remains a topic for future research (but see also Mameli & Bateson, 2006).

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Finally, the chapters of this thesis have highlighted a number of mechanisms that might play a role in children's developing action perception. The existence of each of these mechanisms was investigated in carefully designed and controlled experiments. However, in daily life, humans do not rely on only one of these mechanisms, but likely on all of them. That suggests that these mechanisms dynamically interact with each other to result in adaptive and successful behavior (cf. Thelen & Smith, 1994). Additionally, research has provided evidence for considerable intra-individual variability in psychological functioning (e.g., Molenaar & Campbell, 2009; van Dijk & van Geert, 2007). Although this thesis systematically examined the impact of different mechanisms on young children's action perception, it is limited, as it did not investigate the dynamic interplay between the mechanisms presented here nor their intra-individual variability. It leaves it to future research to adequately address these dimensions of children's developing action perception.

4. Final conclusion

In summary, the present thesis provides clear evidence for the relevance of sensorimotor mechanisms in the early development of action perception and is thus in line with embodied and sensorimotor approaches to human cognition. In contrast, only limited evidence was presented of the impact of the principle of rational action on action perception. The results stress the role of perceptual learning, motor resonance, action-effect binding and affordance perception in infants' and children's cognitive processing of others' actions and in their ability to predict as well as learn from others' behavior.

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Samenvatting (Nederlands)

De ontwikkeling van handelingswaarneming: neurocognitieve mechanismen van informatieverwerking over de handelingen van andere mensen in de kindertijd

Ontwikkelingspsychologisch onderzoek heeft in de afgelopen jaren ons begrip van het handelingsbegrip bij kinderen sterk vergroot. Zo is bijvoorbeeld aangetoond dat kinderen al in het eerste levensjaar menselijke handelingen wellicht anders verwerken dan fysieke gebeurtenissen. Bovendien is gebleken dat baby's anticiperen op de handelingen van anderen en door observatie kunnen leren. Dat wordt duidelijk in hun imitatie van de handelingen van andere mensen. Deze resultaten van deze studies zijn vruchtbaar geweest voor de ontwikkelingspsychologie. Ze hebben geleid tot de formulering van een aantal nieuwe theorieën over de ontwikkeling van het handelingsbegrip en van imitatie.

Het doel van dit proefschrift was om een aantal van de invloedrijkste theorieën over actie perceptie bij kinderen te toetsen. Daartoe zijn 9 experimentele studies uitgevoerd met kinderen tussen 8 maanden en met volwassenen, waarbij gebruik is gemaakt van verschillende onderzoeksmethoden zoals gedragsmetingen in imitatie- en reactietijdexperimenten, de registratie van kijkgedrag - met op infrarood licht gebaseerde eye-tracking methoden - en electrofysiologische metingen van de hersenenactiviteit.

In de eerste studie werd een eye-tracking paradigma gebruikt om te onderzoeken of handelingsanticipatie bij 9 maanden oude kinderen en volwassenen wordt beïnvloed door perceptueel leren of het nadenken over de efficiëntie van de handelingen van anderen. De deelnemers aan deze studie zagen op een scherm hoe een agent een lang pad gebruikte om zijn doel te bereiken, omdat een korter (en efficiënter) pad niet begaanbaar was. Wanneer in de daaropvolgende testfase het kortere pad wél begaanbaar was, verwachtten zowel de kinderen als de volwassenen dat de agent nog steeds het lange pad zou nemen. Als deze dan het kortere pad koos, pasten de volwassenen hun anticipatiegedrag aan en anticipeerden naar het kortere pad. De kinderen deden dit echter niet. Dit toont aan dat bij de handelingsanticipatie van zuigelingen perceptueel leren van frequente gebeurtenissen een belangrijke rol speelt, terwijl de handelingsvoorspelling op basis van een beoordeling van de efficiëntie later in de ontwikkeling ontstaat.

SAMENVATTING (NEDERLANDS)

In de tweede studie werd met behulp van elektro-encefalografie (EEG) onderzocht of zuigelingen al bidirectionele handelings-effect associaties kunnen verwerven. Om dit te onderzoeken, kregen kinderen van 8 maanden een rammelaar om gedurende een week mee te spelen. Op deze manier leerden ze een bepaald geluid door eigen handelen te veroorzaken. Daarnaast kregen ze een tweede geluid te horen dat via een voice recorder werd aangeboden, en dat dus niet met een handeling samenhang. Na deze trainingsfase werd met het EEG de hersenenactiviteit van de kinderen gemeten terwijl ze naar de twee bekende geluiden en naar een derde, onbekend, geluid luisterden. Een frequentie-analyse van de data liet zien dat de mu-frequentie band over de motorische cortex sterker gedesynchroniseerd was als de kinderen naar het geluid van de rammelaar luisterden dan als ze de andere twee geluiden hoorden. Dit resultaat ondersteunt de hypothese dat zuigelingen al handelingseffect associaties verwerven. Deze bevindingen corresponderen met bevindingen over audiovisuele spiegelneuronen bij apen.

In de derde studie werd onderzocht of kinderen door observatie kunnen leren, dat een werktuig verschillende functies kan hebben en dat de manier waarop iemand het werktuig vastpakt, voorspelt wat hij ermee gaat doen. Veertien en 20 maanden oude kinderen keken op een eye-tracking monitor hoe een persoon met een werktuig twee verschillende handelingen op telkens twee verschillende doelobjecten uitvoerde. De manier waarop het werktuig werd gepakt en vastgehouden was typisch voor de gebruiksfunctie ervan. Terwijl de 20 maanden oude kinderen op grond van deze informatie in staat waren het goede doelobject te voorspellen, konden de 14 maanden oude kinderen dit nog niet. Cognitieve mechanismen die hier mogelijk aan ten grondslag liggen, zijn statistisch leren, motorische resonantie en het waarnemen van affordances.

De vierde studie onderzocht de ontwikkeling van de vaardigheid om de handelingsmogelijkheden van andere mensen waar te nemen. Kinderen van 2,5, 3,5 en 5 jaar observeerden hoe een actor in verschillende situaties hulp van vrienden nodig had. In iedere situatie waren twee vrienden aanwezig, waarvan er telkens één in staat was hem te helpen. De kinderen werd gevraagd aan wie ze dachten dat de actor hulp zou vragen. De resultaten lieten zien dat alleen de kinderen uit de twee oudere leeftijdsgroepen in staat waren de goede keuze te maken. Daarnaast konden alleen de 5 jaar oude kinderen hun keuze goed beredeneren. Als ten grondslagliggend mechanisme wordt de vaardigheid voor de waarneming van de affordances van andere personen voorgesteld.

SAMENVATTING (NEDERLANDS)

In de vijfde en zesde studie werden twee neurocognitieve mechanismen van imitatie bij zuigelingen onderzocht. Het principe van de rationele handelingen stelt dat zuigelingen al de efficiëntie van geobserveerde handelingen kunnen beoordelen en deze handelingen, afhankelijk van hun efficiëntie, imiteren. Aan de andere tegenstelling wordt gesteld dat motorische resonantie – dat wil zeggen de activatie van het eigen motorisch repertoire door observatie van de handelingen van andere personen - een belangrijke rol speelt in het imitatieproces. In zeven condities werd systematisch gemanipuleerd of de gemodelleerde handeling efficiënt was en of de 14 maanden oude kinderen de waargenomen handeling aan hun eigen motorisch repertoire konden relateren. Een analyse van de reproductie van de geobserveerde handelingen door de kinderen liet zien dat de kinderen de handelingen vaker imiteerden wanneer ze de handelingen aan hun eigen motorische repertoire konden relateren, onafhankelijk van de efficiëntie van het geobserveerde gedrag. Deze bevindingen ondersteunen de conclusie dat motorische resonantie een centrale rol speelt in de imitatie bij zuigelingen.

In de zevende studie werden de bevindingen van de voorafgaande studies samengevat met als doel een model van imitatie in de zuigelingenleeftijd te formuleren en dit model te toetsen. Het gepresenteerde model veronderstelt dat imitatie op de vaardigheid gebaseerd is, dat handelingseffect associaties door observatie te verwerven zijn, en dat zuigelingen vooral handelingen imiteren die tot saillante effecten leiden. Dit model leidt tot de hypothese dat de imitatie van een handeling minder waarschijnlijk is als het kind de handeling niet aan zijn eigen motorische repertoire kan relateren of als de handeling niet tot saillante effecten leidt. De resultaten van de studie bevestigden het model.

De achtste studie toetste de verwerving van bidirectionele handelingseffect associaties op volwassen leeftijd. De deelnemers zagen hoe een ander persoon met twee handelingen telkens een geluid veroorzaakte. In de daaropvolgende testfase reageerden de proefpersonen sneller als ze dezelfde handeling in reactie op de geluiden moesten uitvoeren, wanneer deze eerder de geluiden had veroorzaakt dan wanneer de relatie tussen geluidje en handeling omgedraaid was. Dit resultaat toont aan dat de waarneming van het effect van een voorafgaande handeling het daarmee geassocieerde motorprogramma activeert. De deelnemers hadden daarmee dus een bidirectioneel handelingseffect associatie door observatie verworven.

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In de negende studie werden de corticale mechanismen van het leren door observatie bij zuigelingen met hulp van EEG onderzocht. Op basis van de eerdere bevindingen werd de hypothese opgesteld dat kinderen handelingseffect associaties door observatie kunnen verwerven. Deze zouden op corticaal niveau door associaties tussen de motorische cortex en een verdeeld netwerk voor de representatie van het respectievelijk handelingseffect gerealiseerd zijn. In analogie met de opzet van de tweede studie leerden 9 maanden oude kinderen in een trainingsperiode van een week dat het gebruik van een rammelaar tot een bepaald effect leidt, daardoor dat ze de handelingen van iemand anders observeerden. Gedurende dezelfde week luisterden de kinderen ook naar een andere geluid, dat door een voice recorder werd aangeboden. In de daaropvolgende testfase werd de hersenenactiviteit van de kinderen gemeten, terwijl ze naar de twee bekende geluiden en een onbekend geluid luisterden. Het resultaat toonde een sterkere desynchronisatie aan de mu-frequentieband over de motorische cortex voor het rammelaargeluidje in vergelijking met de andere twee geluidjes aan. Dit betekent dat de waarneming van het rammelaargeluidje tot activatie in de motor cortex leidde en dat het corticale motorische systeem bij het leren door observatie betrokken is.

Samenvattend laat dit proefschrift zien dat mechanismen van perceptueel leren een belangrijke rol spelen in de ontwikkeling van handelingswaarneming. Dit geldt vooral voor statistisch leren over de frequenties van handelingen (Hoofdstuk 2) en de affordances van andere personen (Hoofdstuk 5). Bovendien werd aangetoond dat zuigelingen eigen handelingservaringen gebruiken bij het verwerken van informatie over de handelingen van andere personen (Hoofdstuk 3). Dit is waarschijnlijk ook bij de handelingsvoorspelling belangrijk (Hoofdstuk 4). De studies over imitatie en leren door observatie laten zien dat imitatie op de zuigelingleeftijd toe te schrijven is aan motorische resonantie en het leren van handelingseffect associaties (Hoofdstukken 8, 10) en niet aan rationele afwegingen (Hoofdstukken 6, 7). Dit mechanisme speelt waarschijnlijk ook een rol in het leren door observatie op volwassen leeftijd (Hoofdstuk 9). De studies in dit proefschrift tonen dus aan dat perceptuele en motorische processen een belangrijke rol spelen in de zich ontwikkelende handelingswaarneming.

Zusammenfassung (Deutsch)

Die Entwicklung der Handlungswahrnehmung: Neurokognitive Mechanismen der Verarbeitung der Handlungen Anderer im Kleinkindesalter

Entwicklungspsychologische Forschung hat in den letzten Jahren unser Verständnis der frühkindlichen Handlungswahrnehmung massiv erweitert. So haben Befunde beispielsweise nahegelegt, dass bereits Kinder im ersten Lebensjahr menschliche Handlungen anders verarbeiten als physikalische Ereignisse. Darüber hinaus wurden Nachweise erbracht, dass Kleinkinder Handlungen anderer Menschen antizipieren sowie durch die Beobachtung von Handlungen lernen und diese imitieren können. Diese Studien waren sehr gewinnbringend für die entwicklungspsychologische Theoriebildung, da sie zur Formulierung einer Anzahl einflussreicher Theorien über die Entwicklung des Handlungsverständnisses und der Imitation geführt haben. Ziel der vorliegenden Arbeit ist es, einige prominente sozialkognitive und neurokognitive Mechanismen der Handlungswahrnehmung im Kleinkindesalter systematisch zu überprüfen. Unter Verwendung von Verhaltensmaßen in Imitations- oder Reaktionszeitparadigmen, der Registrierung kindlichen Blickverhaltens mit Hilfe von auf Infrarotlicht basierten Eye-Trackern sowie elektrophysiologischer Korrelate der Gehirnaktivität wurden neun experimentelle Studien mit Kindern im Alter von 8 Monaten bis 5 Jahren sowie Erwachsenen durchgeführt.

Die erste Studie untersuchte die Hypothese, dass bereits junge Kinder die Erwartung haben, dass eine andere Person effizient handelt. Alternativ wurde vorgeschlagen, dass assoziatives Lernen von Häufigkeiten, der zentrale Mechanismus der Handlungsantizipation im Säuglingsalter ist. Der Einfluss dieser Mechanismen auf die Handlungsantizipationen von 9 Monate alten Babys und Erwachsenen wurde in einem Eye-Tracking-Paradigma erforscht. Die Teilnehmer dieser Studie beobachteten auf einem Bildschirm, wie ein sich ueber den Schirm bewogender Protagonist einen langen Weg nahm, um sein Ziel zu erreichen, da der kürzere (d.h., effizientere) Weg nicht begehbar war. Als in der darauf folgenden Testphase der kürzere Weg verfügbar war, erwarteten Kinder wie Erwachsene im ersten Testtrial, dass der Protagonist noch immer den längeren Weg nehmen würde. Als er jedoch den kürzeren Weg zum Ziel wählte, veränderten die Erwachsenen, nicht aber die 9 Monate alten Kinder, in den folgenden Trials ihr Antizipationsverhalten und zeigten visuelle Antizipationen zum

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kürzeren Weg. Diese Befunde legen nahe, dass im Säuglingsalter perzeptuelles Lernen die Handlungsvorhersage dominiert, während Handlungsvorhersagen auf Grund einer Beurteilung der Effizienz möglicher Handlungen ein späteres Entwicklungsprodukt sind.

In der zweiten Studie wurde mit Hilfe von Elektroenzephalographie (EEG) erforscht, ob bereits Säuglinge in der Lage sind, bidirektionale Handlungs-Effekt-Assoziationen zu erwerben. Zu diesem Zweck spielten 8 Monate alte Kinder eine Woche lang mit einer Rassel und lernten dabei, dass sie durch ihre eigene Handlung ein bestimmtes Geräusch verursachten. Gleichzeitig wurden sie mit einem zweiten Geräusch vertraut gemacht, welches von einem Voicerecorder dargeboten wurde (und daher nicht handlungsrelatiert war). Nach dem Training wurde das EEG abgeleitet, während die Kinder die zwei bekannten sowie ein neues Geräusch hörten. Eine Frequenzanalyse der Daten ergab, dass die Kinder eine stärkere Desynchronisation im mu-Frequenzband über dem motorischen Kortex zeigten (d.h., motorische Aktivierung), wenn sie das Rasselgeräusch wahrnahmen im Vergleich zu den zwei anderen Geräuschen. Dieser Befund unterstützt die These, dass bereits Kinder im Säuglingsalter Handlungs-Effekt-Assoziationen erwerben, und korrespondiert Untersuchungen über audiovisuelle Spiegelneuronen bei Affen.

Ziel der dritten Studie war es zu untersuchen, ob Kinder durch Beobachtung lernen können, dass ein Werkzeug unterschiedliche Funktionen erfüllt und dass die Weise, wie es gegriffen wird, prädiktiv ist für seinen weiteren Gebrauch. Vierzehn und 20 Monate alte Kinder verfolgten auf einem Eye-Tracking-Monitor, wie eine Person mit einem Werkzeug zwei unterschiedliche Handlungen an je einem anderen Zielobjekt durchführte. Die Art, wie das Werkzeug gegriffen und gehalten wurde, war dabei kennzeichnend für seinen weiteren Gebrauch. Während die 20 Monate alten Kinder in der Lage waren, aufgrund dieser Information das richtige Zielobjekt vorherzusagen, war dies den 14 Monate alten Kindern nicht möglich. Mögliche zugrunde liegende kognitive Mechanismen könnten statistisches Lernen, die Wahrnehmung von Affordances und sein.

Die vierte Studie untersucht die Entwicklung der Fähigkeit, die Handlungsmöglichkeiten einer anderen Person wahrzunehmen. Dazu beobachteten Kinder im Alter von 2,5, 3,5 und 5 Jahren, wie ein Protagonist in unterschiedlichen Situationen die Hilfe von Freunden benötigte. In jeder Situationen waren zwei Freunde anwesend, von denen jeweils einer physisch fähig war (bspw. groß genug oder stark genug), ihm zu helfen. Die Kinder wurden gefragt, wen der Protagonist um Hilfe fragen würde. Es zeigte sich, dass nur die Kinder in

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den zwei älteren Altersgruppen dazu imstande waren, den richtigen Freund zu wählen. Darüber hinaus waren nur die 5-jährigen Kinder in der Lage, ihre Wahl korrekt zu begründen. Diese Ergebnisse zeigen, dass Kinder ab 3 Jahren fähig sind, die Handlungsmöglichkeiten anderer wahrzunehmen. Dies beruht wahrscheinlich auf der Fähigkeit, die Affordances anderer Personen wahrzunehmen.

In der fünften und sechsten Studie wurden zwei neurokognitive Mechanismen der Imitation im Säuglingsalter überprüft. Das Prinzip rationaler Handlung besagt, dass Kinder die Effizienz beobachteter Handlungen beurteilen und Handlungen entsprechend ihrer Effizienz imitieren. Demgegenüber wurde vorgeschlagen, dass Motorresonanz (d.h. die Aktivierung des eigenen motorischen Repertoires durch die Beobachtung der Handlungen anderer) eine zentrale Rolle im Imitationsprozess spielt. In sieben Bedingungen wurde systematisch manipuliert, ob die modellierte Handlung effizient war oder nicht und ob die 14 Monate alten Babys die wahrgenommene Handlung auf ihr eigenes Motorrepertoire beziehen konnten oder nicht (das bedeutet, ob sie zu Motorresonanz führte oder nicht). Eine Analyse der kindlichen Reproduktion der beobachteten Handlung zeigte, dass die Babys die Handlung dann häufiger imitierten, wenn sie sie auf ihr eigenes Motorrepertoire beziehen konnten, unabhängig von ihrer Effizienz. Diese Befunde legen nahe, dass Motorresonanz eine zentrale Rolle in der kindlichen Imitation spielt.

Ziel der siebten Studie war es, die Befunde der vorhergehenden Studien zusammenzufassen, ein Modell der Imitation im Säuglingsalter zu formulieren und die Vorhersagen dieses Modells zu überprüfen. Das präsentierte Modell geht davon aus, dass Imitation auf der Fähigkeit beruht, Handlungs-Effekt-Assoziationen durch Beobachtung zu erwerben, und dass Säugling vor allem Handlungen imitiert, die zu salienten Effekten führen. Dieses Modell führte zu den Hypothesen, dass die Imitation einer Handlung dann weniger wahrscheinlich ist, wenn sie durch das Kind entweder nicht auf das eigene Motorrepertoire bezogen werden kann oder wenn sie nicht zu einem salienten Effekt führt. Die Ergebnisse der Studie waren im Einklang mit diesen Vorhersagen und bestätigten das Modell.

Die achte Studie überprüfte den Erwerb von bidirektionalen Handlungs-Effekt-Assoziationen durch Beobachtung im Erwachsenenalter. Die Teilnehmer sahen, wie eine andere Person wiederholt durch zwei Handlungen je einen auditorischen Effekt auslöste. Es zeigte sich, dass die Versuchspersonen in der darauf folgenden Testphase schneller reagierten, wenn sie die gleichen Handlungen als Reaktion auf die Töne ausführten, die zuvor durch diese Handlung

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verursacht wurden, als wenn die Zuordnung zwischen Ton und Handlung umgekehrt war. Dies zeigt, dass die Wahrnehmung des Effektes einer Handlung das damit assoziierte Motorprogramm aktiviert und dass die Versuchspersonen eine bidirektionale Handlungs-Effekt-Assoziation durch Beobachtung erworben hatten.

In der neunten Studie wurden die neuralen Grundlagen des Beobachtungslernens im Säuglingsalter mit Hilfe von EEG untersucht. Aufbauend auf den vorherigen Untersuchungen wurde die Hypothese aufgestellt, dass Kinder durch Beobachtung Handlung-Effekt-Assoziationen erwerben. Diese sollten auf kortikaler Ebene durch Assoziationen zwischen dem motorischen Kortex und einem distribuierten Netzwerk für die Repräsentation der jeweiligen Handlungseffekte realisiert sein. Analog zum Design der zweiten Studie lernten 9 Monate alte Säuglinge während einer einwöchigen Trainingsperiode, dass der Gebrauch einer Rassel ein bestimmtes Geräusch verursachte, indem sie die Handlung einer anderen Person beobachteten. Zeitgleich wurden die Kinder mit einem weiteren Geräusch vertraut gemacht, welches von einem Voicerecorder abgespielt wurde. In der darauf folgenden Testphase wurden die Hirnströme der Versuchspersonen aufgezeichnet, während ihnen die zwei bekannten Geräusche sowie ein neues Geräusch dargeboten wurden. Die Kinder zeigten eine stärkere Desynchronisation im mu-Frequenzband über dem motorischen Kortex für das Rasselgeräusch (im Vergleich zu den anderen zwei Geräuschen). Dies bedeutet, dass die Wahrnehmung des Rasselgeräusches zu einer Aktivierung des motorischen Kortex führte und dass das kortikale Motorsystem beim Lernen durch Beobachtung eine wichtige Rolle spielt.

Zusammenfassend zeigt die vorliegende Arbeit, dass perzeptuelle Mechanismen - vor allem assoziatives Lernen über die Häufigkeit der Handlungen anderer (Kapitel 2) und die Wahrnehmung der Affordances anderer Personen (Kapitel 5) - eine wichtige Rolle in der sich entwickelnden Handlungswahrnehmung spielen. Darüber hinaus konnte gezeigt werden, dass im Säuglingsalter eigene Handlungserfahrungen die Verarbeitung der Handlungen anderer beeinflussen (Kapitel 3) und wahrscheinlich auch für die Handlungsvorhersage wichtig sind (Kapitel 4). Die Studien zur Imitation und zum Lernen durch Beobachtung legen nahe, dass kindliche Imitation auf Motorresonanz und den Erwerb von Handlungs-Effekt-Assoziationen zurückzuführen ist (Kapitel 8, 10) und weniger auf rationale Abwägungsprozesse (Kapitel 6, 7). Dieser Mechanismus spielt wahrscheinlich auch eine Rolle im Beobachtungslernen im Erwachsenenalter (Kapitel 9). Diese Studien legen nahe, dass perzeptuelle und motorische Prozesse eine zentrale Rolle in der Verarbeitung von Informationen über die Handlungen anderer spielen.



Curriculum Vitae

Markus Paulus was born on the 12th of May 1980 in Landsberg am Lech (Germany) and grew up in Penzing, a village in Upper Bavaria. He attended secondary education at the Rhabanus-Maurus Gymnasium St. Ottilien. From 2000 on he studied psychology, philosophy, sociology, Italian literature, and history at the KU Eichstätt-Ingolstadt in Eichstätt (Germany), interrupted by a term abroad at Oulu University (Finland). During his studies he received a scholarship of the Friedrich-Ebert Stiftung. He worked as a student assistant for Siegfried Lamnek at the chair of sociology and empirical social research, as a tutor for statistics and experimental research internships at the chair of cognitive psychology and research methodology (Edward Haub) and from 2006 until 2007 as assistant of the vice-president of the university of Eichstätt, Stefan Schieren. He graduated 2006 in psychology with a diploma (master) thesis on infants' developing physical knowledge under supervision of Petra Hauf at the Max-Planck Institute for Human Cognitive and Brain Sciences in Munich. 2007 he graduated in philosophy (with distinction) with a master thesis on Habermas and Foucault under supervision of Reto Fetz.

From 2007 to 2011 he did his PhD research with Sabine Hunnius and Harold Bekkering at the Donders Institute for Brain, Cognition and Behaviour, Radboud University Nijmegen (The Netherlands). His research focused on the development and the neurocognitive mechanisms underlying children's processing of others' actions. In particular, he investigated infants' and children's ability to anticipate and to learn through the observation of others' actions. In 2010 he spent 3.5 months as a visiting researcher in the lab of Chris Moore in Halifax (Canada), investigating children's prosocial development. From September 2011 on, he will be working as a post-doctoral researcher in the lab of Beate Sodian at the LMU Munich.

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ACKNOWLEDGEMENTS

Acknowledgements [Dankwort]

There is no scientific work that is not embedded in continuous exchange with others. I'd like to thank the entire Action and Neurocognition Group at the Donders Institute for discussions and valued feedback over the last few years. I'm particularly grateful to: Sabine and Harold, for a very fruitful collaboration, for having shown me how science works and for having created a marvelous research environment; Oliver, for many theoretical discussions and feedback, from which this work benefitted a lot; Michiel, for helping me get started, for shared adventures in Iowa and Des Moines, and for being a great colleague; Iris, for a successful collaboration; Mathieu, for statistical advice; Marlene and Janny, for keeping up the developmental aspect in our group and for a good time on many occasions. Wessel, thanks for being such a great and cheerful office mate and for always lending an ear.

I really enjoyed my work at the Baby Research Center (BRC) with fabulous colleagues. With great pleasure I remember our Christmas parties and our barbecues. Although I'm indebted to the whole team, I would like to emphasize my thanks to the following people: Birgit, without whom I would have ended up being homeless in Nijmegen, for many joint conference visits and for being an exemplary person and scientist; Paula, for her constant kindness and for supporting my first steps into research on language acquisition; Ralf, affiliated with the BSI, for many in-depth discussions on dynamic systems theory and perception-action links; Nicole, for sharing our subjects, for always offering me a place to sleep and for acquainting me with the Düsseldorfer Karneval; Christine, for excellent feedback, whenever I needed it, and for being a great friend; Angela, who is not only very good in degustating my (red wine) cakes and an excellent proofreader, but without whom the atmosphere at the BRC wouldn't have been the same for me.

This research would not have been possible without technical and administrative support. I would like to thank the ERG group and the Instrumentmakerij, especially Gerard, Andre, Pascal, Mark and Norbert; and our administrative support team: Beppie, Yvonne, Saskia, Maaike, and Johanna. Furthermore, supervising students was a great experience and I probably learned as much from them as I was able to teach them; thanks to Marlies, Carolien, Fiepje, Christina (whom I still owe a dinner), Gunda Carina, Samantha, Loes, Clementine, and Guusje.

ACKNOWLEDGEMENTS

I am in great debt to two other people who had an impact on my formation: Chris, thanks for taking care of me in Canada and for the great time I had with you, Steph, Amanda and Beth. I really appreciated our discussions and I really enjoyed (and still enjoy) working with a truly developmental psychologist; Petra, I greatly appreciate (and take this leaf out of your book) that you, even when I was just your intern at the MPI in Munich, always treated me as a colleague, gave me freedom to find my own way into research and supported me whenever I needed your advice. Thanks for everything!

Many thanks to the colleagues and friends at the Donders Center for Cognition (the former NICI). It was a pleasure to spend time with all of you during the weekly volleyball sessions, skiing in Bottrop, the defense parties, the sailing weekend in Friesland or at the vrijdagmiddagborrel. Evelien and Majken, thanks for many shared dinners and “koffies”, and for your help in various situations. Sybrine, Dimi, Anne, Cordula, Nadia, and Lisa, I really enjoyed our shared time, our biketours through the Netherlands and Germany, our evenings in the Lux, and I’m looking forward to our holiday in bella Italia.

Living in the Netherlands wouldn’t have been the same without Claudia, Sandra, Matthew and Willeke. Claudia, from our first steps in the Dutch language, through the NT2 and until today I’m glad to have met you and that we became friends; Sandra and Matthew, thanks for a good and enjoyable time in the Jacob Canisstraat; Willeke, it’s a real shame that I met you so late, but without you I wouldn’t have enjoyed the advantages of parsnips, Christmas tree tags and Blof.

Es gibt natürlich noch ein Leben außerhalb der Wissenschaft und eine ganze Reihe von Personen, mit denen ich größere oder kleinere Abschnitte des Lebenswegs geteilt habe und die mir sehr wichtig sind. Das Dankwort einer wissenschaftlichen Qualifikationsarbeit ist jedoch nicht der rechte Ort, um dies auszudrücken. Eine kleine Ausnahme möchte ich jedoch machen und die Chance ergreifen, um meinen Eltern Dank zu sagen für all ihre Unterstützung in den Jahren des Studiums und der Promotion (und für so vieles, vieles mehr). Ihnen beiden sei diese Arbeit gewidmet.

Markus Paulus



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